# Economic analysis of the installation of biogas plants in dairy farms: a Finnish case study

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Master's thesis
AGERE Master's program
Environmental and Resource Economics Study track
Department of Economics and Management
University of Helsinki
May 2020

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# Acknowledgements

I would like to thank the University of Helsinki for providing me with the opportunity to study a dynamic, relevant and challenging Master's degree. The Master's in Agricultural, Environmental and Resource Economics has taught me the fundamental skills of economic analysis, resource management, climate policy, management of aquatic ecosystems and numerical modelling. This thesis was completed in a time period of approximately 6 months and was made possible thanks to the support and assistance from my thesis supervisors: Professors Timo Sipiläinen and Stefan Bäckman. Their guidance and expertise in dairy farms were essential for this research. We had many meetings and many discussions about the net present value and internal rate of return of the biogas plants. Academic discussions, of course. Kiitos paljon!

Secondly, I would like to thank everybody who participated in the Helsinki Centre of Sustainability Science (HELSUS) first co-creation lab. Thanks to the facilitators Kaisa Korhonen, Arttu Jokinen and William Smolander for organizing the lab sessions. *Arigatou gozaimashita* (Thank you) to my lab supervisor Dr. Michiru Nagatsu for helping me understand the science of co-creation and its abundant research applications. A big thank you to my biogas focus group colleagues, Mirjami Ylinen and Zhao Chuanhui, it was a pleasure to share a common goal and work together in finding the best way to address the societal challenge of the carbon footprint of dairy farming. Together we steered our research towards a more extensive analysis. I found your areas of study to be very useful, specially energy policy and biogas diet potentials. Furthermore, I have to thank Valio for collaborating in the research. It takes a lot of commitment to cooperate with the students and try to help mitigate the environmental impact of dairy farming. This shows that the company accepts its responsibility and wants to build a better future for everyone, so I salute Valio for being so transparent and committed since day one. I want to show special gratitude to Valio senior researchers Antti-Pekka Partonen and Soila Kananen for providing all the data that was needed for this study. Your level of participation was impeccable, I really enjoyed working with you. It was a pleasure to visit the Palopuro agrosymbiosis plant in Hyvinkää. Thanks to Robert Harmoinen, Master's thesis candidate at Valio and proud dairy farmer, for helping me find the electricity costs of a cow farm. It was a nice ride to Hyvinkää! Special regards to Bartosz Bartczyszyn and Bernardino Albiol from Aczia Biogas (El Puig, Valencia, Spain) for mentoring me during Summer 2019 and teaching me the fundamentals of biogas business development, it was an amazing traineeship experience.

On a personal note, I would like to thank my family, specially my parents, Leo and Alicia for encouraging me through my studies. I would not be where I am if it wasn't for your love and support. Also to my sister Andrea for being an awesome little sister and making me laugh. To my auntie Merche for showing me the meaning of resilience and courage. Thank you Ngoc for always being there for me.

Additionally, I thank all my friends and family (which are too many to write down) for their constant support. Last, but not least, I would like to thank Rocky, Misi and Slipo, my faithful companions.

| Tiedekunta – Fakultet – Faculty<br>Faculty of Agriculture and Forestry | | Koulutusohjelma – Utbildingsprogram – Degree Programme<br>Agricultural, Environmental and Resource Economics (AGERE) |
|---|---|---|
| Tekijä – Författare – Author<br>David Huisman Dellago | | |
| Työn nimi – Arbetets titel – Title<br>Economic analysis of the installation of biogas plants in dairy farms: a Finnish case study | | |
| Oppiaine/Opintosuunta – Läroämne/Studieinriktning – Subject/Study track<br>Environmental and Resource Economics (ERE) | | |
| Työn laji – Arbetets art – Level<br>Master's of Science (M.S.) | Aika – Datum – Month and year<br>May 2020 | Sivumäärä – Sidoantal – Number of pages<br>54 |

Tiivistelmä – Referat – Abstract

Dairy farms account for a large portion of the greenhouse gas emissions in the planet. Since cow manure provides a good medium for anaerobic digestion, this study analyzes the economic feasibility of installing a biogas plant adjacent to a 200-cow farm in Finland. The farms in this study produce only cow manure and grass silage to feed the digester. This paper focuses in comparing different scenarios such as electricity production for farm needs and the production of biofuels such as compressed biomethane as an additional business activity. After designing the farm economic model and the biogas installation, we provide an economic analysis of each scenario. The first one shows that it is not feasible to run the biogas business model based only on electricity savings for the farm. The second one proves that additional revenue streams such as biofuel production can revitalize and strengthen the financial model of the plant. Then, the sensitivity and reliability of the model is discussed by providing reasons (i.e. Finnish electricity tariff system) for the outcome of the results. The model reinforces the idea that farms must base their biogas business model on alternative side-streams and do not rely on energy production only. For further research, it is recommended that real life farm business models are incorporated as input data and a proven plant and CHP engine energy balance is secured.

Avainsanat – Nyckelord – Keywords
Biogas, biofuel, electricity, bioenergy, dairy, farms, manure, digestion, grass silage, bioenergy, circular economy

Ohjaaja tai ohjaajat – Handledare – Supervisor or supervisors
Timo Sipiläinen, Stefan Bäckman

Säilytyspaikka – Förvaringställe – Where deposited
University of Helsinki E-Thesis (digital thesis publisher)

Muita tietoja – Övriga uppgifter – Additional information
The thesis is part of the first edition of the HELSUS Co-creation Lab at the Helsinki Centre for Sustainibility Science. The theme is ”integrating circular economic models in biogas plants” and the partner enterprise is Finnish dairy company Valio.

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# 1. Introduction

This chapter introduces preliminary information concerning the Master's thesis topic, scope and activities. Comprised by a general background, goals and boundaries, it addresses the project fundamentals and the main societal problems. The thesis intends to seek, explore and consider ways to tackle problems that affect society from a economic perspective.

## 1.1. General Background

Dairy is an integral part of human civilization. Ever since wild oxes were domesticated in the Middle Euphrates Valley (currently Iraq, Iran and Syria) by ancient Neolithic settlements circa 10,500 years ago, society has relied on milk for sustenance (Bollongino, et al., 2012). The nutritious food is a staple in global gastronomy and an important part of the agricultural development in many countries. Cow farming however, comes at a cost.

Over the last century, an exponential increase in population has led to a surge in the dairy product demand. Cows as ruminants perform methanogenesis during the digestion process, producing greenhouse gas methane as a result. This has led to a situation where cattle farming is responsible for 17% of the global methane emissions and circa 35% of the total anthropogenic emissions (Knapp, et al., 2014). According to a 2007 life cycle assessment by FAO, the total GHG emissions from cattle farming were 1969 million tones $CO_2$-eq, where milk production was responsible for 1328 million $CO_2$-eq or 67% of the total cattle farming emissions (Food and Agriculture Organization of the United Nations, 2010). This scenario has pushed governments to address the societal challenge from a sustainability approach, aiming at reducing methane emissions without compromising the economic opportunities that dairy products provide to the national and regional sectors.

Cows tend to excrete fecal matter in large quantities. During farming high amounts of cow feces are produced and stored. Cow manure and slurry (both animal by-products) are rich in organic compounds such as organic carbon and nitrogen. Traditionally, cow manure has been directly applied to crop fields serving as an organic fertilizer (Bernal, et al., 2009).

However, cow manure can serve in other ways. Biogas production consists in the aerobic digestion of organic matter through methanogenic bacteria which produce biomethane, a natural gas that can be used as fuel after purification. Biogas reactors require to be fed a diet rich in stabilizing agents, such as cow manure, which contains a rich mix of different microbial species. The introduction of different bacteria from bovine origin allows the digestor to maximize methane production. Recent research has proven that the key lies in the presence of green bacteria such as *Azotobacter sp.* and *Pseudomonas sp.* both present in cow dung (Gupta, et al., 2016).

For this reason, many cattle farms are starting or considering to incorporate biogas farms into their business model. The direct availability of raw material in comparison to fossil fuels for energy production, can benefit farms in terms of energy independence and waste utilization. A priori, a circular economic model is established enhancing sustainability within the dairy farms and the possibility of producing other products (biofertilizers) from the biogas digestate. Circular economy (Ce) is a regenerative economic model which is based in the idea of re-using and recycling the generated by-products during the production process, closing the production loop and generating extra value to the production chain (Vanhamäki, et al., 2019).

In Finland, dairy company Valio is studying ways to incorporate biogas plants to small scale farms placed throughout the national territory. Founded in 1905, the company is aiming towards a carbon-neutral milk chain by 2035. Biogas is at the core of Valio's interests regarding greenhouse gas mitigation and carbon footprint reduction (Kaukovirta-Norja, 2019). As many options exist concerning biogas plant business models, such as biofertilizer and biofuel production, a preliminary economic analysis is sought after. The Helsinki Centre of Sustainability Science (HELSUS), Valio and the University of Helsinki established the first edition of the HELSUS Co-creation lab, a platform centered in addressing societal challenges through cross-discipline collaboration.

To analyze the economic feasibility of the different potential models concerning biogas plants by-products such as biofuels is the fundamental task of this Master's thesis.

## 1.2. Goal

The goal is to analyze the economic feasibility of a small-scale biogas installation in a dairy farm (200 cows) during a 20-week study, in order to observe the potential business opportunities of different scenarios such as energy and compressed biomethane production.

### 1.2.1. Sub-goals

- To set-up an economic balance of two different business scenarios to be established in the farm. Biofuel production and self-use of generated electricity as main elements to analyze. The biogas plant produces biogas only from cow manure and grass silage.
- To critically analyze and discuss the best possible scenario from an economic perspective.
- To ultimately address the societal challenge of reducing the carbon footprint of dairy farming and enhancing the circularity of the Finnish agricultural sector.

## 1.3. Boundaries

The thesis scope is limited to:

- Economic analysis of a dairy farm of the no more than 200 cows. The farm economic balance is provided by the literature, given that no real life data is obtained, a simulated scenario of a typical 200 cow farm economic model will be used.
- Due to the time frame of the research, a selection of business scenarios will be selected and presented in the method chapter.
- Biogas production and input will be standardized during the economic calculations based on company data and assumptions such as a diet based primarily on manure and additional products.

## 1.4. Reading guide

The thesis report compiles the following chapters:

- <u>Chapter 2 – Theoretical background:</u> articles an journal findings are summarized and presented in the theoretical background chapter. The main research questions regarding biogas production, dairy farming and circular economy are addressed.
- <u>Chapter 3 – Method:</u> the business model and its different scenarios are explained in this chapter. It includes the assumptions and formulas used to calculate the economic elements in the model and the design features.
- <u>Chapter 4 – Results:</u> in this chapter the results obtained through the economic analysis of the business models are presented and explained.
- <u>Chapter 5 – Discussion:</u> this chapter discusses the results obtained from the researcher's perspective, considering scientific analysis and methodology used. Furthermore, it addresses if the goals have been reached according to plan.
- <u>Chapter 6 – Conclusion:</u> the conclusion acts as a summary of the findings and compiles all the essential information obtained during the research and execution of the Master's thesis.

# 2. Theoretical Background

This chapter compiles the necessary information to address the research questions and ultimately answer the project thesis and reach the aforementioned goals. The literature is obtained from scientific articles and journals.

## 2.1. Circular Economy

Circular economy (CE) is an economic model of regenerative nature which is characterized by idea of closing the production loop. By redirecting by-products and waste products back into the production phase, the demand for new resources is reduced. There are two main approaches or subcategories within CE which define the nature of the means of production: biological and technical cycles.

The biological cycle contains resource of organic nature, where a flow of nutrients can be established. The Ellen McArthur Foundation states that the biological streams undergo conversion in a 'natural and renewable manner', or in other words, are capable of undergoing renewable practices such as restoration and regeneration. This thesis focuses on the biological cycle, due to the organic nature of the cattle farm by-products. On the other hand, the technical cycle is focused on the non-organic side of the product spectrum. Materials from mineral origin or not fit for biological conversion undergo renewable practices such as recycling, refurbishing, maintenance and reuse (The Ellen MacArthur Foundation, 2008).

Both streams work together towards the same objective: reducing the waste ending up in the landfills. Anaerobic digestion is an important part of the biological cycle, making biogas a major enabler of sustainable practices within circular economy. Circular economy applied to biological streams is often referred to as *bio-based circular economy*.

### 2.1.1. Circular economy framework and guidelines

In order for circular economy to be successfully implemented on a national level, it must follow certain guidelines. In his 2011 article *Environmental Sustainability: a definition for environmental professionals*, researcher John Morelli describes a series of suggestions which governments and producers are set to follow in order to successfully implement a circular model (Morelli, 2011):

1. **Rebranding waste** – In order to change the perception of waste among consumers, waste is rebranded as useful and valuable. By-products, secondary resources or food for production are alternative names to the word *'waste'*.

2. **Saving energy** – following the rules of thermodynamics, by-products contain energy either invested in (through its production) or that can be invested on energy producing processes such as incineration of methane. In circular economy, conserving energy is a fundamental part of the sustainable approach. By keeping energy within a product life cycle (let's say milk or cheese), the efficiency of its production is increased and environmental costs reduced.
3. **Policies and regulations** – integrated to the national policies, circular economy laws should focus on the producers and the consumers equally. Targeting polluters is an effective way of reducing landfill use and environmental pollution. Measures that extend responsibilities are deemed compatible with a regenerative economic model as way to educate society the value of by-products.

### 2.1.2. Circular economy business models

Circular economy is a concept, which has not been standardized by definition. This means that there are a variety of definitions and its theoretical perspective can be ambiguous (Geissdoerfer, et al., 2017). However, a practical approach to understanding circular economy is by analyzing the business models through its internal and external networks. Internal networks are those corresponding to the supply chain and internal activities within a company. On the other hand, external networks are those established among the customer groups and the final end product. In the case of Valio, the farmers and milk production are part of their own value network whilst milk and milk consumers are their customer value network. Therefore, the economy can be classified into four different business models (Urinati, et al., 2017):

- **Linear –** based on the traditional economic model where by-products and products end up discarded. No use is found in produced goods after they have been used. There is no external nor internal values and production efficiency is low.
- **Downstream circular –** circularity is achieved only on the customer value network, meaning it focuses on the final phase of the product's life-cycle. Common practices within this scope of action are recycling, restoring and reusing.
- **Upstream circular –** main focus on circularity takes part solely on the production process. High internal value and increased production efficiency. By having a circular beginning of the product life-cycle, its environmental impacts are reduced.
- **Fully circular –** there is circularity integrated into the whole product life-cycle meaning there is a high internal and external network value.

### 2.1.3. Circular economy in Finland

Finland has embraced the concept of circular economy into its national policies by establishing *The Finnish Roadmap toward Circular Economy 2016-2025*. This framework proposed by Sitra reveals an integrative approach to regenerative economy, where closing the loop is addressed and integrated into every dimension of the nation's economy. Through the development of economic tools and new technology aimed at enabling the repurposing of production by-products (or waste), Finland expects to be a leading nation in sustainable practices by 2025 (SITRA, 2016).

There is a special mention to the development of sustainable food systems. By reducing the waste and carbon footprint generated by the agriculture sector, Finland is setting the pathway towards sustainable governance. In this way, the main focus lies on nutrient recycling as the key to change. The agricultural sector is experiencing a shift in its production modus operandi leaning towards sustainable food production. Practices like less energy and water consumption, lower waste generation and reintroduction of the by-products back into the nutrient cycle, are encouraged within the industry. Furthermore, consumer behavior in Finland is widely open towards sustainable production. On a study by Salonen et al. (2014), *Sustainable Consumption in Finland—The Phenomenon, Consumer Profiles, and Future Scenarios,* researchers found out that in Finland there is a shift in consumer behavior where product added value is slowly becoming the purchase enabler or determining factor over price. The influence of Finnish circular economy regulation will lead to irresponsibly-produced products to be the expensive option, since costs of externalities associated to pollution and waste generation will affect the price. Finnish consumers are generally more aware of the added value of sustainable shopping. As the author explains, money spent on sustainable agriculture has the ability to promote nutrition, public health and animal well-being as well as benefiting the local community. Circular economy links producers and consumers more tightly within the product life-cycle, almost as in a form of trust which fuels social change and makes people more aware of the finite planet (Salonen, et al., 2014).

## 2.2. Biogas technology

Anaerobic digestion, also known as biomethanization, is a metabolic process which occurs in conditions where oxygen is lacking. Methanogenic bacteria in combination with fermentative and hydrogen producing acetogenic bacteria digest organic matter (input) into two main by-products: biogas and digestate.

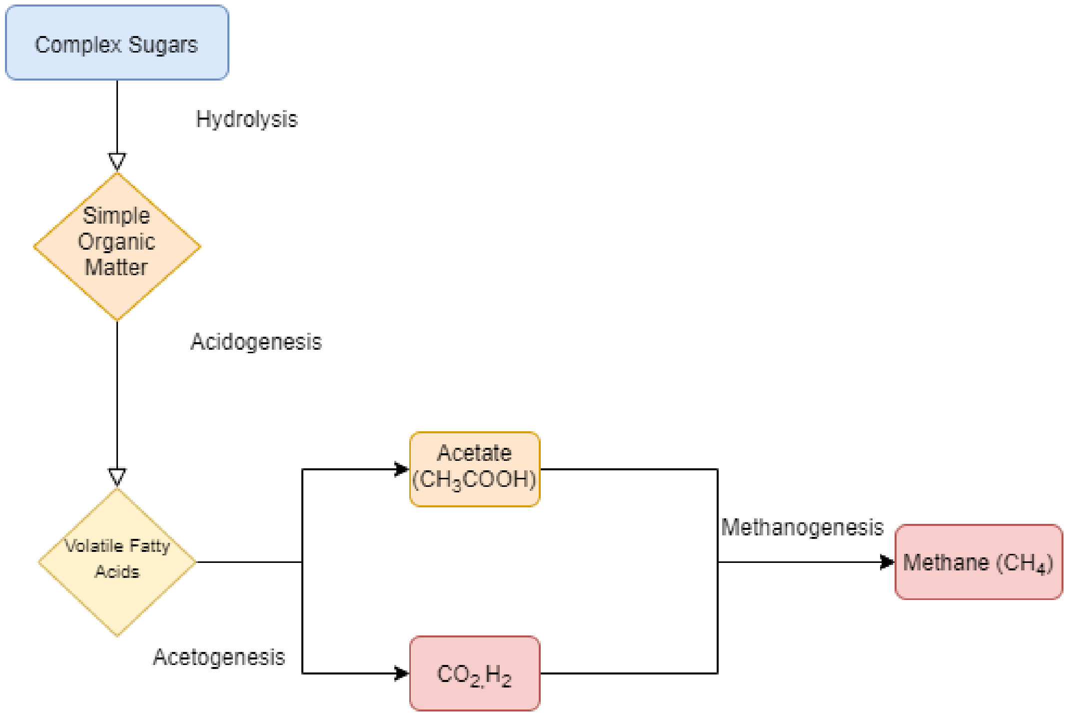


*Figure 1 - Methanogenesis metabolic process (David Huisman Dellago, based on the paper "The Genome of M. acetivorans Reveals Extensive Metabolic and Physiological Diversity" (Galagan & Nusbaum, 2002)).*

Complex sugars present in the diet are broken down to simple organic matter by hydrolysis. Through acidogenesis, the fatty acids are isolated form the organic matter. This process involves the fermentative bacteria. Volatile fatty acids then undergo acetogenesis, thanks to the hydrogen producing acetogenic bacteria, where an alcohol (acetate), carbon dioxide and hydrogen are released. These compounds are then converted to methane through methanogenesis. Within a biogas plant this process takes place in the bioreactor.

Biogas is a fuel comprised by methane ($CH_4$) and carbon dioxide ($CO_2$). As previously mentioned, it is created in a process of methanogenesis or anaerobic digestion by specialized bacteria. Its high methane content (between 60-75%) provides biogas with an elevated calorific value. This condition allows, after being upgraded to eliminate metabolic by-products such as sulphuric acid (HS) and water ($H_2O$), to be used in industrial boilers and internal combustion engines. The newly purified biogas is called biomethane and complies with natural gas standards. Cogeneration engines or combined heat and power (CHP) plants transform kinetic energy into electricity and heat.

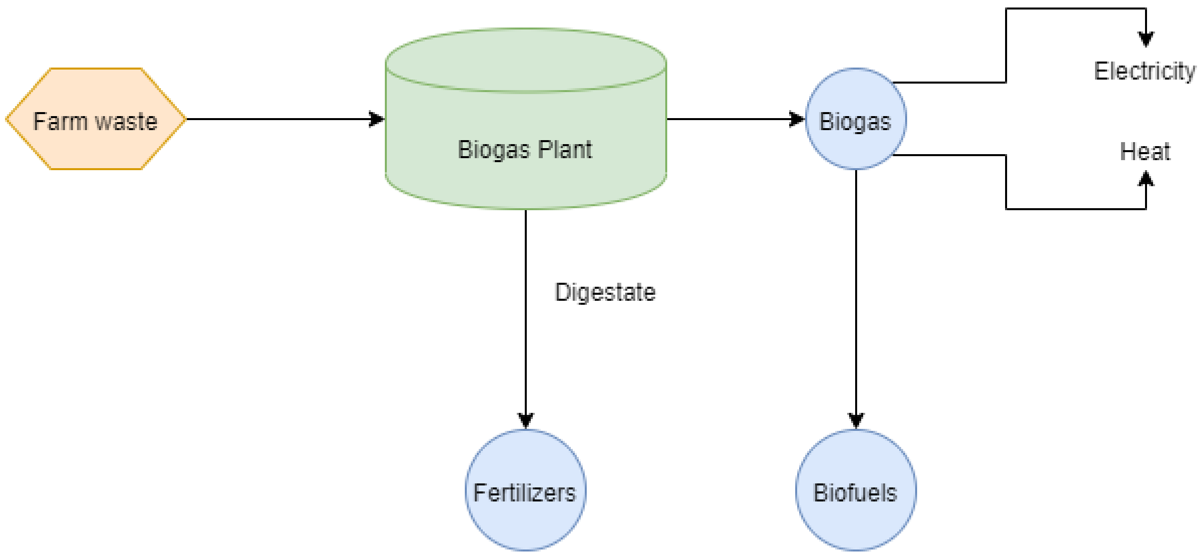


*Figure 2 - Simplified biogas plant process (David Huisman Dellago)*

Overall, biogas' nature makes it a very dynamic source of energy. It can be used to produce heat, electricity and if transformed to compressed biomethane, biofuel for transport vehicles. However, biogas is only one category of products produced by anaerobic digestion as leftover organic matter (known as digestate) can serve as biofertilizer.

### 2.2.1. Biogas plants

Biogas plants are facilities comprised of an anaerobic digester (or bioreactor) that produce biogas by treating biodegradable waste products. Digestate is created as a by-product of the process. The main defining factor in the potential of biogas production is the nature of the diet fed into the bioreactor. Co-digestion combines different biodegradable products in order to increase the biogas potential of the process. For example, cow manure serves as a stabilizer by providing useful bacteria into the system and animal carcasses provide fatty acids and other organic compounds to be broken down into methane. This combination of substrates increases the biogas potential and higher amounts of biogas can be produced.

As far as business design goes, the main goal of a biogas plant is to find the balance between development costs (construction and maintenance) and the facility efficiency (biogas production).

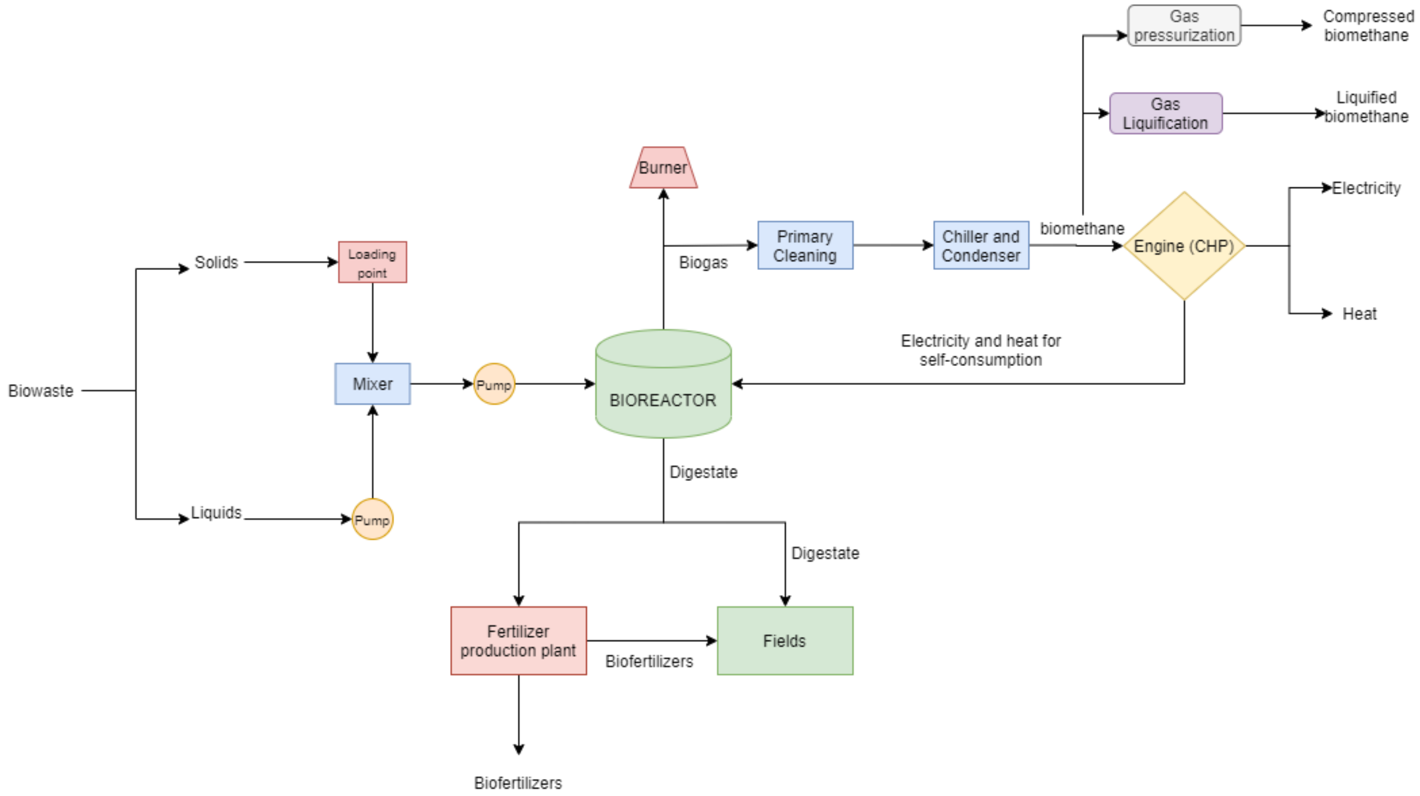


*Figure 3 - Comprehensive biogas plant design (David Huisman Dellago, based on data compiled from the Sustainable Sanitation and Waste Management Toolbox model)*

### 2.2.2. Biogas production

In order to produce biogas, the facilities follow a production process which is in depicted in Figure 3 – Comprehensive biogas plant design. Feeding the plant can be done in two main ways depending on the diet's nature:

- Solid feeding (manure, field waste, garden waste)
- Liquid feeding (slurry, milk production wastewater)

Standard biogas plants are equipped with an interconnected loading unit that feeds the solid waste into the mixer. In the mixer liquid waste is then pumped in and a slurry is formed. The slurry or biowaste mix is pumped into the digester for the digestion process to begin. A centralized pumping system regulates the feeding process of the biogas plant.

**Bioreactor**

The bioreactor, commonly known as digester, is comprised of a cylindrical tank where biowaste is stored and digested by bacteria. Depending on the magnitude of the project, bioreactors vary in size and volume. Anaerobic conditions prevail within the chamber. The biogas produced rises and is collected in a gasometer located in the upper part of the bioreactor. The gasometer itself contains a biogas storage chamber and a collection point (chamber) which is where gas is collected for further treatment.

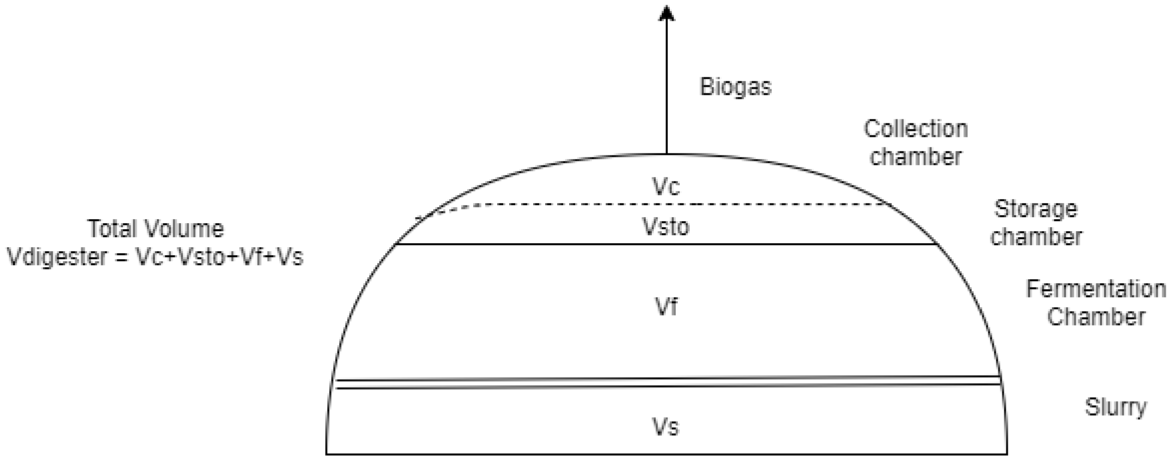


*Figure 4 - Bioreactor diagram. (David Huisman Dellago, based on data compiled from the Sustainable Sanitation and Waste Management Toolbox model)*

When designing a biogas plant, the total volume of the bioreactor is determined by the projected slurry, fermentation space, and storage and collection chamber volumes.

**Heat exchange**

For an adequate fermentation process, a constant temperature of 37°C must be kept within the bioreactor. Biogas plants are equipped with an internal pipeline network that carry hot water and keep the bioreactor at an adequate temperature for the bacteria to biodegrade the feed. The hot water originates from the process of cooling the CHP engine, meaning it is a self-generated source from a closed-circuit industrial process.

**Agitators**

In order to facilitate the fermentation and methanogenesis processes, the slurry is mixed and stirred constantly. A homogenous feed mix improves the biogas production yield. For that reason, biogas plants incorporate two agitators which are generally placed vertically: one on the top and one on the bottom of the digester.

**Biogas treatment**

Biogas produced in the digester contains 60-75% methane ($CH_4$), 20-35% carbon dioxide ($CO_2$) and 1-5% hydrogen ($H_2$), hydrogen sulfide ($H_2S$) and nitrogen ($N_2$) gases. Methane is the gas that feeds the CHP engine and has the highest calorific value, for that reason it must be treated and upgraded prior to its usage in combustion. Furthermore, hydrogen sulfide is a harmful gas that easily corrodes machinery (Abatzoglou & Boivin, 2009). Biogas plants are equipped with upgrading units that clean the biogas and obtain biomethane.

There are two main standard procedures:

- **Activated carbon filter** – used to effectively remove hydrogen sulfide and siloxanes from the biogas produced in the digesters. The porous surface of the carbon in the filter, allows contaminants to adsorb (or be trapped in) to the surface of the filter. After undergoing the filtering, biogas will only contain methane and carbon dioxide (EPA, 2001).

- **Water scrubbing** – this procedure separates biomethane from the rest of compounds present in the raw biogas. Pressurized gas enters a column of water where $CO_2$ and other compounds are absorbed. As methane solubility in water is much lower than the other compounds, high-quality bio-methane (>90% methane content) is obtained. Additionally, biogas is chilled (to 10-15°C) and dehumidified in the process. Overall, the energy production potential is increased as biomethane has the highest calorific value of all the gases present in raw biogas and the engine maintenance costs are reduced, as cleaner biogas (to natural gas standards) lowers the engine corrosion levels (Rotunno, et al., 2017). This concerns both CHP and vehicle engine fuel applications.

## 2.3. Biogas uses

Biogas, after it has been upgraded to biomethane, has many applications at an industrial and commodity level. Methane gas is used as fuel for machinery and transport ever since its discovery as a fossil fuel in the industrial revolution. Biomethane offers the same advantages at methane with the added value of circularity. Being produced from biowaste, it is considered a renewable source of energy as it has little to no carbon footprint.

### 2.3.1. CHP

Combined heat and power (CHP) are a method of simultaneously producing electricity and heat. Heat can be recovered and utilized; thus, it is a cogeneration process. In this case, biogas plants benefit from the possibility of producing its own energy and therefore partially/totally eliminating the need to purchase electricity from the grid.

The engines are powered by the combustion of biomethane which generates mechanical energy that is harnessed by an alternator located within the engine. The cooling system uses a pipe system to transfer heat form the engine onto water.

In terms of efficiency, the CHP engine produces:

- 60% Heat energy
- 40% Electrical energy

The CHP engine produces two heat categories:

- **Low grade heat** – Typically between 70°C and 100°C, available in the form of hot water and it is used to warm up the digesters.
- **High grade heat** – Present as exhaust gas from the engine, it reaches temperatures of up to 450°C and can be used directly in a waste heat boiler for further utilization of heat. Boilers have the capacity of producing steam.

Overall, it has the potential to provide energy self-sufficiency to the biogas plant and other facilities in its proximity.

### 2.3.2. Biofuel options

When it comes to biomethane for fuel for an external medium, rather than the internal CHP within the biogas plant, it must be processed for storage and transport. In this case, the upgraded biogas can be compressed or liquified for external use in vehicle or industrial engines. Specialized stations in the biogas facility allows for the production of the following fuels:

- **Compressed biomethane** – methane is compressed to up to 1% of its atmospheric pressure volume providing a higher storage efficiency. It can be used for natural gas vehicles such as cars, trucks and buses. The Helsinki Metropolitan Area bus fleet counts with up to 1000 biogas-fueled buses. Furthermore, there are several compressed biogas service stations for cars and trucks all around Finland, many of which provide compressed biogas. This service is mainly carried out by gas company GASUM.

  Compared to diesel or petrol fuels, compressed biomethane emits 25% less $CO_2$, 80% less hydrocarbons and up to 90% less nitrous oxide (NOx). Its organic origin, in the case of biomethane, makes it an attractive business model for sustainable development and a relatively environmental-friendlier option than traditional fuels.

A compressing station is installed in biogas plants where biomethane (upgraded biogas) is processed and compressed into gas containers at a 20-25 Mpa pressure. The containers can then be distributed to fueling stations throughout the Finnish territory for sale and consumption. Among biofuel options, it is considered the easiest and cheapest alternative. There is potential for plants with smaller biomethane production (Shah, et al., 2017).

- **Liquified biomethane** – in this case, methane is liquified using a cryogenic technique. The gas is condensed at temperatures below -162°C where it reaches a liquid state and is stored in gas tanks at a pressure of 25 kPa. It is primarily used in heavy duty transport vehicles such as ship vessels or heavy trucks. It is considered the cleanest greenhouse gas available due it its low carbon, nitrogen and hydrocarbon emissions when combusted (Shah, et al., 2017).
  Regarding biogas plants, it requires a larger investment as well as maintenance, operation and logistical costs. This is due to the fact that gas must be treated at very low temperatures with energy demanding technological processes. A cryogenic unit is needed to condense and liquefy biomethane. This heavy logistic investment makes it only suitable for large scale biogas plants. For example, in Europe, the Lidköping biogas liquefaction plant in Sweden has a production of 13 Tn/d and the Bioland plant in Italy has a production of 10 Tn/d of liquefied biomethane (Ulvestad & Overland, 2012).

## 2.4. Dairy farms in Finland

Dairy farms are agricultural installations that specialize in the production of milk to be later processed and sold as dairy products. Examples include pasteurized milk, yogurt and cheese (Mussel, 2018). Finland, being the nation with the highest consumption of milk per capita in the world (**361 kg/person/year**), has a large dairy sector which the rural communities depend on (LUKE - Natural Resources Institute Finland, 2015).

It is estimated that in 2020 there are 5000 farms in the country, with an average of 50 cows per farm. However, the projections within the sector suggest that number of farms are decreasing but increasing in size. If compared to other countries such as the United Kingdom and the Netherlands, the size of Finnish farms are relatively small on average. On a global scale, the US has an average herd size of

200 cows, whilst the U.K has 150 and Canada 80. The herd size varies across farms therefore considering Valio's farms size, they have large herd sizes for Finland (200 cows in this study). According to a recent report by the FAO (Food and Agriculture Organization), in 2018 Finland produced an average of **9,795 kg milk/cow/year** and it is estimated that there are **270,000 cows** in total (FAOStat, 2018). Luke discloses that milk production is directly linked to beef production, as calves born in dairy farms are bred for meat (LUKE - Natural Resources Institute Finland, 2015).

### 2.4.1. Energy demands in dairy farms – Biogas challenge

Dairy farms follow different routines for production depending on the time of the year. This is reflected in its energy demand, which is not synchronized. Electricity and heating demands vary greatly among each other. Whilst heating demand fluctuates throughout the year, electricity demand is relatively constant as lightening is needed during the winter and ventilation fans are used during the summer. During the cold Finnish winters, heating demand surges considerably whilst in summers it drops as temperatures rise and the cattle can roam in the pastures.

**Relation with biogas production**

A study by Marttinen et. al, called *Rural biogas: feasibility and role in Finnish energy system*, showed the relationship between energy production of a biogas plant in a Finnish dairy farm (4300 tn/y manure production; 150 tn/y grass silage) and the energy demand.

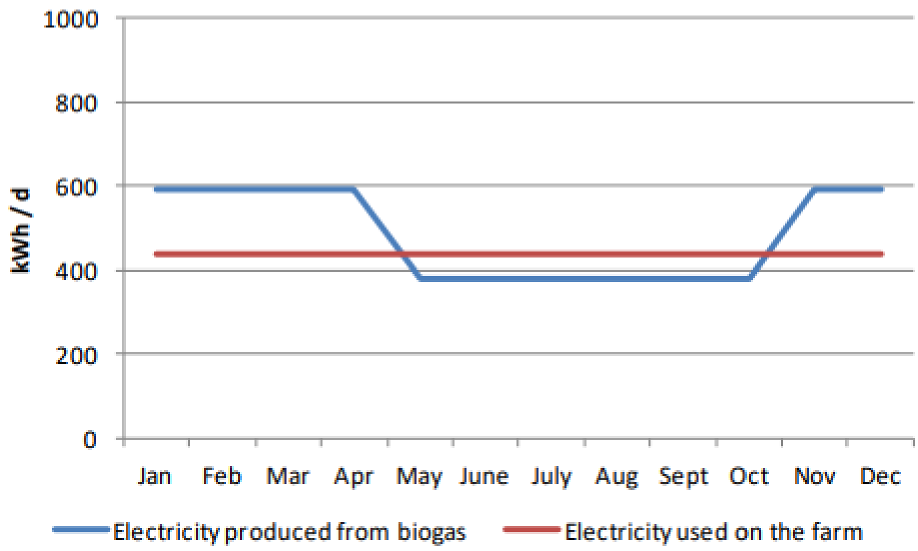


*Figure 5 - relationship between electricity production and electricity demand throughout the year in a Finnish dairy farm (Marttinen et al., 2015)*

Figure 5 shows that electricity used on the farm stays constant throughout the year, as it is used for lightening and ventilation. However, the electricity produced from biogas drops during the warmer periods as cows roam the pastures and it is harder to collect manure. This can pose a challenge for mono-substrate feeds where manure is the major biowaste material to produce biogas. For this reason, it is preferred to have a varied diet to feed the bioreactor. On a 200 cow farm however, it is very likely that cows do not roam the pastures but are rather kept on an enclosure, even during summer.

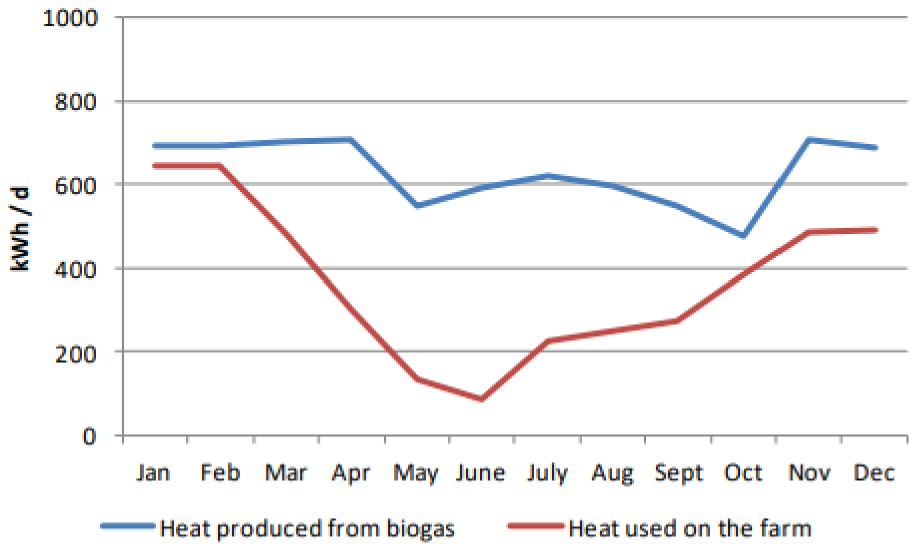


*Figure 6 - relation between thermal energy demand and thermal energy production in a Finnish dairy farm (Marttinen et al., 2015)*

On the other hand, thermal energy demand tends to drop during the summer since the farm requires less heating. Heat produced from biogas is usually always higher than the demand, so the consumptions is covered throughout the year. Once again, the manure deposited in the pastures by the cows during the warmer period, reduces the energy production by the biogas plant.

*Figure 7 - Overview of Palopuron Biokkasu Oy biogas plant in Hyvinkää (Finland). The plant produces 2500 MWh worth of compressed biogas per year. It is comprised of two bioreactors and follows a dry fermentation process. (Metener Oy, 2018).*

## 2.5. Subsidies in Finnish biogas projects

Finland is leaning towards a carbon neutral future for its industry and is incorporating different schemes aimed at encouraging the construction of renewable energy plants (SITRA, 2016). Biogas is considered renewable since it works primarily on biowaste, a secondary resource obtained from other economic activities.

The country mainly operates using investment subsidies which are applicable for investments made by a business (farm, factory etc.) aiming at covering their own energy demands. Other policies which act as investment accelerators are feed-in tariffs and feed-in premiums.

Feed-in tariffs offer a long term contract for energy purchase (similarly to Power Purchase Agreements) in order to establish a secure revenue scheme for a renewable energy plant. The prices are similar to those offered in the wholesale market (to the grid) however they are based on the costs and designed to cover them over time. The prices are above retail to encourage investment. The tariffs regress over the year, encouraging technological costs reductions by the power plant.

Feed-in premiums offer additional bonus over the feed in tariff, an extra amount over the wholesale price to the grid.

For the project depicted in this thesis, only farm-based subsidies are considered. This is due to the fact that the purpose of the biogas plant is to cover electricity costs of the farm and produce biofuel as a marketable product. The subsidies in Finland vary and can cover up to 40 % of the capital expenditure on a case-by-case basis. The prerequisites for this kind of investment are:

1. Plant must have an minimum efficiency of 70 %
2. Financial plan must be presented in advance

The subsidies are regulated by the Finnish Energy Authority (*Energiavirasto*) and they offer the following grants:

- <u>Electricity capacity</u> – **4,300 €/kW** of rated electricity produced by the plant.
- <u>Thermal capacity</u> – **800 €/kW** of rated thermal energy produced by the plant.

By calculating the electrical and thermal energy capacity of the biogas plant, the investment subsidy can be obtained. As usual, bigger and more efficient plants are prone to a larger investment grant in comparison to the smaller projects (Energiavirasto, 2019).

# 3. Method

This chapter depicts the methods used for the economic analysis of the installation of a biogas plant in a Finnish dairy farm. For this purpose, the calculations, data gathering plans and Excel spreadsheet design are explained in detail.

## 3.1. Method overview (Excel Spreadsheet)

The economic analysis in this study has the ultimate objective to study the feasibility of a biogas plant for a 200 cow dairy farm use. By setting up an economic balance of the different business units (farm, biogas plant, compressed biomethane plant and biofertilizer plant) a clear depiction of the associated profits and costs can be observed.

The feasibility factors are:

1. **Internal rate of return (IRR)** – it is a measurement that calculates the return on the investment over a certain time period. In this case, a percentage of the total investment is depicted on an annual basis or in other words, how much of the initial investment is returned per year (Bodie, et al., 2004).
2. **Pay-back time** – the pay-back time shows how many years it will take for the initial investment (CAPEX) to be recovered. Simply speaking, it translates the IRR to units of time such as months or years. For this study, the pay-back time is expressed in years (Brealey, et al., 2006).
3. **Net present value (NPV)** – the NPV measures the feasibility of an investment by calculating the future cash flow of the model (e.g. biogas plant fertilizer unit) and discounts the initial costs of investment (CAPEX included) from the future cash flow. A substantial NPV means that it is favorable to invest in a certain asset as it will bring future value that makes the investment worthwhile (Bodie, et al,. 2004). The formula describes the NPV in more detail:

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$$

Where:

- R= the current net cash flows of the installation
- t= time period
- i = discount rate

The summation of 20 years gives a single value which is the NPV, expressed in euros. The higher the NPV the more favorable the investment is.

In Excel however, we use the following formula:

*= NPV (discount rate, (annual net cash flow sum) + net cash flow year 0)*

The use of an Excel spreadsheet is the main modus operandi behind the study. Every business unit is included in the form of a scenario, which adds or decreases value to the main farm economy. Every installation is seen as an investment with its associated finance plan. Elements such as installments and interest rate are categorized in the study to add realism to the economic scenarios.

[NOTE] – All units (farm, biogas plant & compressed biomethane plant) act as a single business owned and managed by Valio's associated farmers. In other words, all the business units are controlled by the same party and its costs and revenues from daily operations land in the same business holding.

**Scenarios**

The following scenarios are designed to cover every possible application the biogas plant has to offer to a dairy farm. In this

- **Scenario 0 -** base, no biogas processing. Farm embodied as energy associated costs when not having a biogas plant.
- **Scenario 1 -** Biogas plant [CHP for electricity; Digestate not processed] – heat and electricity generation through CHP to produce heat and electricity to power the farm demand.
- **Scenario 2 -** Biogas plant [Compressed biogas; CHP for electricity; Digestate not processed] – biogas produced is compressed and sold as compressed biogas. Biogas plant has to purchase electricity from the grid.

## 3.2. Scenario 0 – Farm Design

The farm is designed according to the standard Finnish dairy production and energy demand. The farm economy (economic balance) acts as the base scenario which can be compared to the rest of biogas-related scenarios. A solid foundation to build the business model around.

The following categories are used to design the farm economy:

General assumptions:

- 200 cows
- No other animal farming (focused on mainly on cow milking)
- Other activities such as crop production are considered

DATA GATHERING:

- Manure production (Tn/year)
- Energy demand
  - Electricity (MWh/year)
- Costs
  - Electricity (€/year) – electricity costs based on demand.

Since the study focuses on the changes in energy costs and investment feasibility, the revenue streams from the farm are not taken into account (as they do not change or influence the scenarios directly). Only electricity is considered for the farm (as an energy demand) since thermal energy covers other aspects such as fuel consumption and operating machinery. The thermal energy produced by the biogas plant is used for the heating of the bioreactor only.

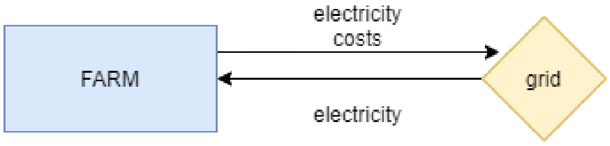


*Figure 8 - Scenario 0. Farm business model (David Huisman)*

The electricity demand of the farm is calculated by using data available from the literature.

## 3.3. Biogas Plant Design

The design of the biogas plant is made according to the principles and factors described in the theoretical background. The most important factors are:

i. **Biogas plant feed (diet)** – the feed is the biowaste which will be inputted into the bioreactor. The diet design determines the biogas yield which can then be used to calculate the energy generation by the CHP engine (electricity) and compressed biomethane production.
   The input initially consists of cow manure and biowaste from crop production. The crop production biowaste is available in the form of silage and garden cuttings. When designing the input it is important to consider:

   - Most common crops farmed in Finland within dairy farm's arable lands.
   - Potential biowaste that can be utilized as feed to accompany the manure.

   For this study, two main products are considered: cow manure and grass silage. Cow manure is obtained directly from the cattle at a rate of 5000 Tn/year. The grass silage on other hand is grown in the fields belonging to the farm, specifically for feeding the cows and producing biogas. An opportunity cost of grass silage production is incorporated in the financial balance.

   Feed specifications:

   - Cow manure – 5000 Tn/y
   - Grass silage – 500 Tn/y (based on a 1:10 manure-to-silage ratio for biogas optimization (Marttinen, et al., 2015).

   The following design and technical features are obtained:

*Table 1 - Biogas plant design features*

| BIOGAS PLANT | | |
|---|---|---|
| NUMBER OF DIGESTORS | 2.00 | |
| VOLUME OF EACH DIGESTOR | 1,222.22 | m3 |
| TOTAL VOLUME OF THE DIGESTORS | 2,444.44 | m3 |
| TOTAL FEEDING (BIOWASTE + WATER) | 61.11 | m3 |
| WATER VOLUME | 45.83 | m3/day |
| DAILY FEEDING BIOWASTE | 15.28 | Tn/day |
| RETENTION TIME | 40.00 | days |
| ANNUAL FEEDING BIOWASTE | 5,500.00 | Tn/year |
| BIOGAS HOUR PRODUCTION | 44.26 | Nm3/hour |
| BIOGAS ANNUAL PRODUCTION TOTAL | 387,741.94 | Nm3/year |
| BIOGAS TO CHP (adjusted to farm demand) | 61,186.77 | Nm3/year |
| BIOGAS LEFTOVER OR TO COMPRESSED BIOGAS | 326,555.17 | Nm3/year |

ii. **Biogas production** – Once the diet has been designed and the biogas potential calculated based on the different biowaste materials, the biogas production is obtained. The biogas production is calculated the following way:

1. Obtaining the Total Solids (TS %) and Volatile Solid (VS %) ratios of a certain biowaste category (E.g. cow manure). This can be found in the literature.
2. Obtaining the methane production potential of a certain biowaste category ($m^3$ $CH_4$/kg VS). This can be found in the literature.
3. Calculating the mass of VS present in a ton of biowaste (kg VS/ton biowaste). This is obtained by multiplying the VS% and the TS% ratios and then expanding to tonnes by multiplying by 1000.

$$VS\% * TS\% * 1000 = \textit{Volatile solid mass (kg VS/ ton of biowaste)}$$

4. Calculating the total methane produced per ton of biowaste by multiplying the mass of VS present in a ton of biowaste with the methane production potential.

$$VSmass * \textit{methane production potential} = \textit{methane production of feed } (Nm^3\textit{/ton of biowaste})$$

5. Calculating biogas production by diving the methane production of feed by the average methane content in biogas.

$$\frac{Methane\ production\ of\ feed}{average\ methane\ content\ in\ biogas} = Biogas\ production\ (Nm^3\ biogas/ton\ of\ biowaste)$$

The average methane content in biogas is **62%.**

6. Finally, the total biogas annual production is calculated by multiplying the biogas production per ton of biowaste by the total annual production of biowaste.

*Total biogas production (Nm$^3$/year) = Biogas production (Nm$^3$ biogas/ton of biowaste)* total biowaste production (tonnes/year)*

This calculation can be applied individually per biowaste category and then summed up to obtain the total biogas production (yield) of the feed.

Therefore, for a 5000 Tn/y cow manure and 500 Tn/y grass silage feed, the following biogas yield is obtained:

*Table 2 - Biogas potential table feed*

| | MANURE 2 | GRASS SILAGE | TOTAL |
|---|---|---|---|
| **VS(%)** | 0.73 | 0.75 | |
| **TS(%)** | 0.22 | 0.25 | |
| **m^3 CH4/Kg VS** | 0.24 | 0.34 | |
| **VS over TS (kg SV/Tn)** | 160.60 | 187.50 | |
| **Production CH4 (Nm3 CH4/Tn)** | 38.54 | 63.75 | 102.29 |
| **Production BG (Nm3 BG/Tn)** | 62.17 | 102.82 | 164.99 |
| **Production (Tn/year)** | 5000.00 | 500.00 | 5500.00 |

Table 2 shows the potential of the available feed. Grass silage yields a higher potential per ton, almost triples the cow manure potential. This gives a good basis for the production of biogas.

*Table 3 - Energy potential table feed*

| ENERGY POTENTIAL | MANURE | GRASS SILAGE | TOTAL | ADJUSTED (needed for CHP only) |
|---|---|---|---|---|
| **Nm3 BG/m3 substrate** | 62.17 | 102.82 | | |
| **PCI (Kcal/m3 BG)** | 5,480.00 | 5,480.00 | | |
| **PCI adjusted (kWh/m3 BG)** | 6.37 | 6.37 | | 6.37 |
| **Nm3 BG/year** | 310,838.71 | 51,411.29 | 362,250.00 | 61,186.77 |
| **kWh/year** | 1,979,772.35 | 327,445.22 | 2,307,217.57 | 389,759.70 |
| **kW/year** | 247.47 | 40.93 | 288.40 | 48.72 |
| **MW/year** | 0.25 | 0.04 | 0.29 | 0.05 |
| **p electricity (MW/year)** | 0.099 | 0.016 | 0.115 | 0.019 |
| **p thermal (MW/year)** | 0.148 | 0.025 | 0.173 | 0.029 |

- <u>Biogas plant technicalities</u> – the technical data regarding the biogas plant design features is gathered and applied on a practical level. Some examples include:
  - Number of digesters
  - Volume of digester ($m^3$) – the volume each digester must have in order to maximize production.
  - Total volume of digesters (m3) – the total accrued volume of the installation.
  - Daily feeding ($m^3$/day) – how much feed goes into the system on a daily basis.
  - Annual feeding ($m^3$/year) – how much feed goes into the system on a yearly basis
  - Biogas hourly production ($m^3$/hour) – production of biogas every hour.
  - Biogas annual production ($m^3$/year) – production of biogas every year.
  - Electricity self-consumption by components (kWh/year) – how much electricity is consumed by the biogas plant and the CHP engine.
  - Electricity available for direct use (kWh/year) – electricity available after used by the system.
  - Electricity demand from farm (kWh/year) – electricity needed by the farm for its operations on yearly basis.

- <u>Volume calculation</u>:

  The volume of the digesters is calculated based on the desired retention time and water-to-feed ratio. The standard retention time is 40 days for an optimal biogas production. The following formula is applied:

$$Total\ Volume\ (m3) = Daily\ feeding\ \left(\frac{m3}{d}\right) * Retention\ time\ (d)$$

First, the daily feeding is obtained from dividing the total annual biowaste feed (5500 Tn/y) by the operating days which are 360 days. This leaves us with a biowaste feed of 15.28 Tn/day.
However, biowaste cannot be pumped by itself, it requires water to be transported smoothly along the system. The standard water-to-feed ratio is 1:3, this means for every ton of feed that enters the system, requires roughly 3 $m^3$ of water. Therefore, the system requires 45.83 $m^3$/day of water. A total of **61.11 $m^3$** of feed is pumped daily into the digesters.

Now the total volume can be calculated accordingly:

i. $Total\ Volume\ (m3) = 61.11\frac{m3}{d} * 40\ d$

ii. $Total\ Volume\ (m3) = 2444.44\ m3$

iii. $Volume\ per\ digester\ (m3) = \frac{Total\ Volume\ (m3)}{number\ of\ digesters}$

If we consider 2 digesters for digestion optimization and circulation of feed, the volume of each digester is:

i. $Volume\ per\ digester\ (m3) = 1222.22\ m3$

## 3.4. Scenario 1 – Biogas to CHP

For scenario number 1, it is important to consider gathering data based on the biogas plant design together with the embodiment of the processes associated with the CHP engine:

- CHP electrical power – the electricity (kW) potential the engine has to supply the farm with electricity.
- CHP thermal power - the thermal potential to produce thermal energy for the digester.
- CHP operating hours – the time the engine will be running on an annual basis. For this study we consider 8000 hours per year.
- CHP electricity production – annual production (kWh/y) of electricity according to operating hours (8000 hours).
- CHP electricity consumption – how much electricity the engine consumes (kWh/y).

Secondly, the yearly financial balance (20 years) is set in order to study the effects on the farm economy. The average biogas plant operates for 20 years, thus, as long as the plant is operating it can revenue and the payback of the investment is ongoing:

- Operating costs (OPEX) biogas plant – estimated at 1 % of the CAPEX, in €/year.
- Capital expenditure (CAPEX) biogas plant - total investment biogas plant, including a financing table of 20 installments with an interest rate of 4%. Conservative figures allow a more realistic outcome.
    - Subsidy calculation

      The calculations for the investment grants are based on the figures seen in Chapter 2.6. The electric and thermal capacities of the plant are obtained from the CHP engine figures and the biogas potential. The following table shows the calculation process:

*Table 4 - Subsidy calculation*

| Subsidy calculation | |
|---|---|
| Electricity (EUR/kW) | 4,300.00 € |
| Thermal Output (EUR/kW) | 800.00 € |
| Electricity capacity (kW) | 19.49 |
| Thermal capacity (kW) | 29.23 |
| Electricity (EUR) | 83,798.34 € |
| Thermal (EUR) | 23,385.58 € |
| Total subsidy | 107,183.92 € |
| Total subsidy (% of total investment) | 13.40% |

Based on a **800,000 €** investment, the subsidy of **107,183.92 €** will account for **13.40%** of the total investment. Costing the farm about **692,000 €** out of their own pockets (or as a credit loan).

- The opportunity costs of growing grass to feed the digester (as grass silage) - This is obtained by calculating the revenue from selling grass silage in the market at the desired quantity. In this case we assume that 100% of the grass silage fed into the system is grown by the farm (500 Tn/y). Costs are calculated the following way:

i. $Total\ dry\ matter\ silage\ \left(\frac{kg}{year}\right) = 25\% * 500{,}000\,\frac{kg\ grass\ silage}{year} = 125{,}000\,\frac{kg\ dry\ matter}{year}$

ii. $Price\ D.M.grass\ silage\ \left(\frac{€}{kg}\right) = 0.12\,\frac{€}{kg}$

iii. $Opportunity\ cost\ \left(\frac{€}{year}\right) = 125{,}000\,\frac{kg\ dry\ matter}{year} * 0.12\,\frac{€}{kg} = \mathbf{15{,}000}\,\frac{€}{\mathbf{year}}$

An opportunity cost of **15,000 euros** per year is considered in the study.

- Cash flow and financial indicators
  - Net cash flow accounting for the revenues minus the costs on each year.
  - Cumulative cash flow as accrued throughout the years. Basically, the net cash flows are added together each year and shown as an accumulated figure under each year calculation.
  - IRR – as a percentage on a 20 year period.
  - Net present value (NPV) – with a discount rate equal to the interest rate of the debt funding (4%).

*Table 5 - Biogas plant financing table*

| FINANCING TABLE | | DEBT FUNDING | | | |
|---|---|---|---|---|---|
| | Opening Fees | € 6,928.16 | | | |
| | DEBT | € 692,816.08 | | | |
| | Interest rate | 4.00% | | | |
| | Payment period | 1 | | | |
| | Term | 20 | | | |
| Year | Installment | Interest | Principal of Debt | Balance | TOTAL PAID PER ANNUM |
| 0 | 0 | € 6,928.16 | € - | € 692,816.08 | € 6,928.16 |
| 1 | 1 | € 27,712.64 | € 34,640.80 | € 658,175.28 | € 62,353.45 |
| 2 | 2 | € 27,712.64 | € 34,640.80 | € 623,534.47 | € 62,353.45 |
| 3 | 3 | € 24,941.38 | € 34,640.80 | € 588,893.67 | € 59,582.18 |
| 4 | 4 | € 23,555.75 | € 34,640.80 | € 554,252.87 | € 58,196.55 |
| 5 | 5 | € 22,170.11 | € 34,640.80 | € 519,612.06 | € 56,810.92 |
| 6 | 6 | € 20,784.48 | € 34,640.80 | € 484,971.26 | € 55,425.29 |
| 7 | 7 | € 19,398.85 | € 34,640.80 | € 450,330.45 | € 54,039.65 |
| 8 | 8 | € 18,013.22 | € 34,640.80 | € 415,689.65 | € 52,654.02 |
| 9 | 9 | € 16,627.59 | € 34,640.80 | € 381,048.85 | € 51,268.39 |
| 10 | 10 | € 15,241.95 | € 34,640.80 | € 346,408.04 | € 49,882.76 |
| 11 | 11 | € 13,856.32 | € 34,640.80 | € 311,767.24 | € 48,497.13 |
| 12 | 12 | € 12,470.69 | € 34,640.80 | € 277,126.43 | € 47,111.49 |
| 13 | 13 | € 11,085.06 | € 34,640.80 | € 242,485.63 | € 45,725.86 |
| 14 | 14 | € 9,699.43 | € 34,640.80 | € 207,844.82 | € 44,340.23 |
| 15 | 15 | € 8,313.79 | € 34,640.80 | € 173,204.02 | € 42,954.60 |
| 16 | 16 | € 6,928.16 | € 34,640.80 | € 138,563.22 | € 41,568.96 |
| 17 | 17 | € 5,542.53 | € 34,640.80 | € 103,922.41 | € 40,183.33 |
| 18 | 18 | € 4,156.90 | € 34,640.80 | € 69,281.61 | € 38,797.70 |
| 19 | 19 | € 2,771.26 | € 34,640.80 | € 34,640.80 | € 37,412.07 |
| 20 | 20 | € 1,385.63 | € 34,640.80 | € (0.00) | € 36,026.44 |

Table 5 depicts the financial plan regarding the investment of the farm for the acquisition and installation of a biogas plant. The net investment sum of **800,000** € is based on a quotation offered by different biogas online calculators. By applying a **13.4% subsidy** and a 4 % interest the investment is returned in 20 years with **20 installments**. The subsidy is applied based on the theoretical background insights (see chapter 2.6). This leaves us with a **700,000 €** subsidized investment. These associated costs are applied throughout every single scenario involving a biogas plant installation. The opening fees to start the payment plan are 1% of the total CAPEX and paid only once at the beginning of the process (year 0).

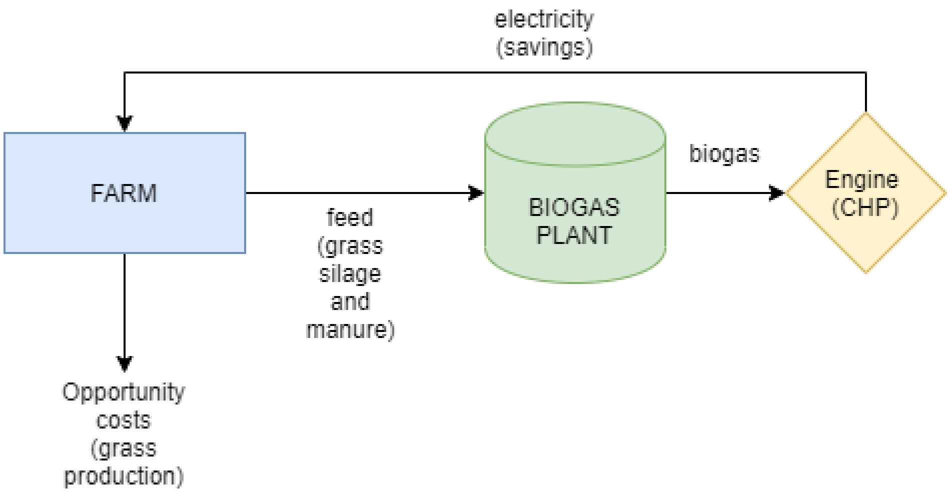

*Figure 9 - Scenario 1. Biogas plant and CHP engine (David Huisman)*

The financial focus of this scenario is made based on the energy savings the CHP engine provides to the farm. By quantifying the yearly savings on electricity, the rate of return of the investment is calculated. Other sources of income or savings derived from surplus electricity were initially considered. However, due to the current Finnish regulations, surplus electricity cannot be sold on the grid as it would affect the biogas plant subsidies on electricity generation. It is not attractive from the farmers to sell the electricity as it would yield very little income. In Finland, if the producer is interested in selling electricity to the grid it has to negotiate a price with the supplier and it is usually less than half of the price of the electricity sold (Marttinen, et al., 2015). In 2011, electricity tariffs were introduced in the Finnish biogas market, where biogas plants could receive income from feeding electricity on to the grid. According to Rolamo and Jarvinen (2017), in 2012, none of the farms biogas plants applied for this system due to the restrictive eligibility requisites. For example, plants that have been built using public subsidies or used second-hand parts for the installation are not eligible. Furthermore, the minimum rated power is set on 100 KvA, making it impossible for biogas plants that run on cow manure and grass silage alone (Rolamo & Jarvinen, 2017).

## 3.5. Scenario 2 – Biogas to CHP and compressed biomethane production

Scenario number 2 evaluates further treatment of the biogas to produce compressed biogas (biomethane) for vehicle and machinery use. The biogas plant costs of investment and maintenance are carried on to this scenario with an additional feature which is the compressed biogas plant. The treatment plant is composed by an activated carbon filter system, chiller for biogas purification, blower to transport the biogas along the system and a compressor to compress the biomethane. All of these parts carry an energy demand (only electricity) which is included in the total OPEX and a capital expenditure for the construction of the compressing plant. A CHP engine is also installed, however due to its low price compared to the grand picture of the investment, its cost is barely negligible. The engine provides yearly electricity savings to the farm.

For this study, a **100 Nm$^3$** ***PurePac*** treatment plant by Bright Biomethane is considered, based on a rough estimate provided by Jouku Pentinnen from Finess Energy Oy and follow-up calculations (Pentinnen, 2020) (Bright Biomethane, 2020). The original data belonged to a 500 Nm$^3$ PurePac treatment plant, this however, has been scaled down to a fifth of its original dimensions – affecting also the operating costs.

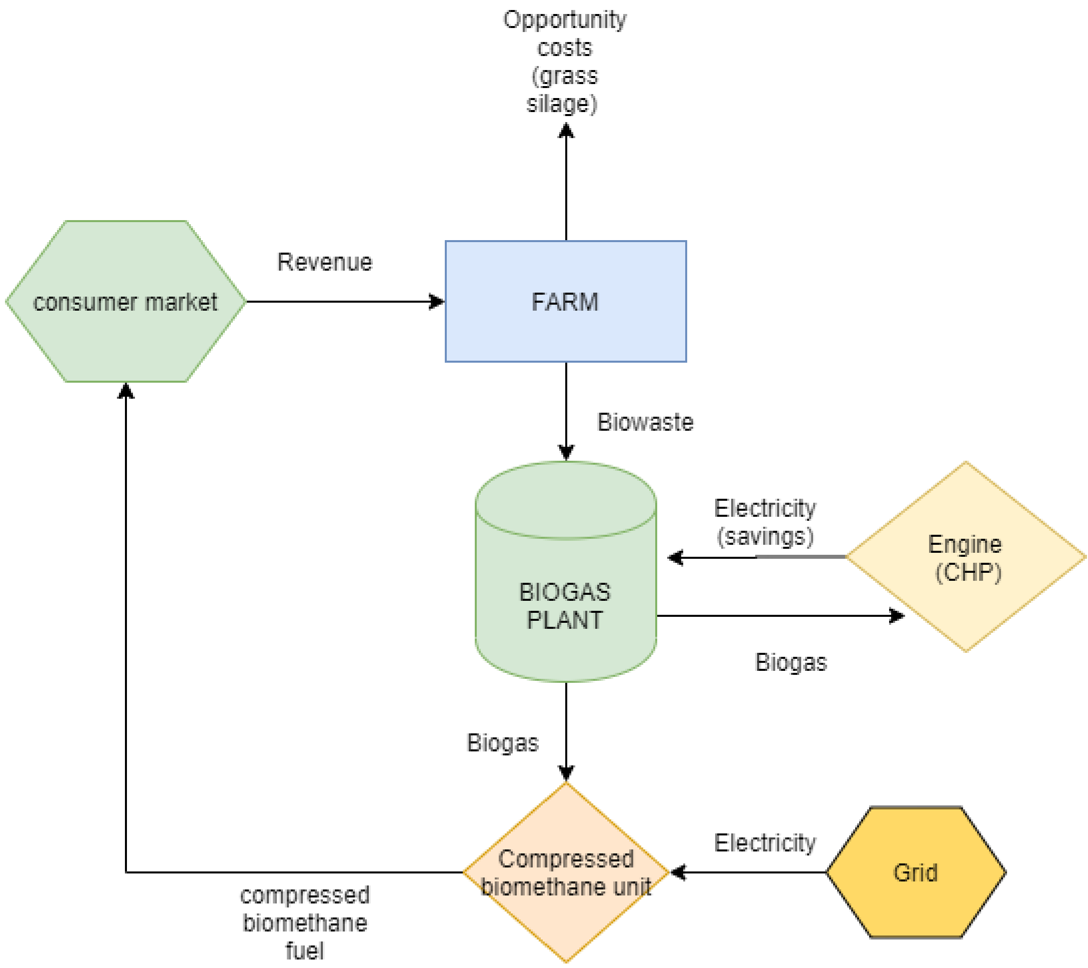


*Figure 10 - Scenario 2. Biogas plant and compressed biogas production (David Huisman)*

For the financial analysis the following data is required:

- **Costs**
  - Compressed biogas plant electricity demand (MWh/year). Within the total electricity demand:
    - Compressor electricity demand (MWh/year)
    - Blower electricity demand (MWh/year)
    - Chiller electricity demand (MWh/year)
    - Other equipment electricity demand (MWh/year)
  - Compressed biogas plant thermal energy demand (Not required for compression of biomethane as heat recovery is included in the system).

- Total OPEX (€/year) – operating costs of running the treatment and compressing plant. This includes operator work for plant supervision and activated carbon material (€/kg and €/year).

  The OPEX is calculated by scaling down a quotation for a **1 M€ plant**. Many operational costs based on materials supply such as activated carbon and maintenance of the machinery, were divided by 5. Other costs such as operator salary and installation are not scaled down as the professionals are paid accordingly no matter the size of the plant.

  The OPEX is broken down and calculated in the following way:

*Table 6 - OPEX Calculation for Compressed Biogas plant*

| Operation and maintenance costs (case Finland) 500 Nm3/h unit and 100 Nm3/unit | | | | |
|---|---|---|---|---|
| | unit | 500 Nm3/unit | 100 Nm3/unit | NOTE |
| Biogas conditions | | | | |
| Methane content | % | 55 | 55 | |
| Availability max. | % | 98 | 98 | |
| | | | | |
| Plant capacity | Nm³/h | 500 | 100 | |
| Availibility % (average) | % | 96 | 96 | |
| Running hours / y | hrs | 8410 | 8410 | |
| Materials and energy needed | | | | |
| | | price € | | |
| Electricity | kWh | 0.08 | 0.08 | |
| Heat | kWh | 0.08 | 0.08 | |
| Active carbon VOC | kg | 3 | 0.6 | |
| Active carbon H2S | kg | 4 | 0.8 | |
| Daily supervision by operator | h | 80 | 80 | |
| Energy consumptions - average outdoor temperature | | | | |
| Blower | kW | 6 | 1.2 | |
| Compressor | kW | 125 | 25 | |
| Chiller | kW | 10 | 2 | |

| | | | | |
|---|---|---|---|---|
| Others | kW | 10 | 2 | kWh |
| Total annual energy consumption | kW | 151 | 30.2 | 253,982.00 |
| Operating costs (EUR/year) | | | | |
| Electricity TOTAL - yearly | | -101,588.00 € | -20,318.56 € | |
| Electric energy - each Nm³ rawgas | | -0.30 € | -0.30 € | |
| Electric energy - each Nm³ productgas | | -0.55 € | -0.55 € | |
| Active carbon costs @ 300 PPM H2S | | -12,052.00 € | -2,410.40 € | |
| Active carbon costs @ 10 mg/m³ H2S | | -432.00 € | -86.40 € | |
| Daily supervision by operator | | -6,400.00 € | -6,400.00 € | |
| Maintenance (incl. wearing parts and oil) | | -29,900.00 € | -5,980.00 € | |
| Heat - yearly | | 0.00 € | | |
| Heat recovery compressor heat | | 47,094.00 € | | |
| THT (odourant) | | -2,186.00 € | -437.20 € | |
| Calibration gas | | -1,472.00 € | -294.40 € | |
| Running cost - yearly | | -106,936.00 € | -35,926.96 € | |
| Running cost each Nm³ rawgas | | -0.025 € | -0.110 € | |

Table 6 depicts the calculations for the 100 Nm$^3$/h biogas compressing and treatment plant. The electricity would be purchased from the grid since it demands more than the bioreactor can actually produce. The system recovers heat and does not require any extra heating from an external source. According to the manufacturer, since this technique delivers the biomethane at **more than 14 bar(g)**, it reduces its energy demand and it is less expensive to operate (more efficient). There is less hassle operating a boiler and reduces the man hours from the operation costs.
Furthermore, the product gas (biomethane) is delivered without $CO_2$ contaminants so there is no need for additional treatment (e.g. bio-bed).

- Total CAPEX (€/year) – an investment is considered based on the quotation estimation offered by the Bright Biomethane product range. As previous examples, the same financing table is used with an **interest of 4%** and a **20 installment** payment option

*Table 7 – compressed biogas plant financing table*

| FINANCING TABLE | | DEBT FUNDING | | | |
|---|---|---|---|---|---|
| | Opening fees | 7,000.00 € | | | |
| | DEBT | € 700,000.00 | | | |
| | Interest rate | 4.00% | | | |
| | Payment period | 1 | | | |
| | Term | 20 | | | |
| Year | Installment | Interest | Principal of Debt | Balance | TOTAL PAID PER ANNUM |
| 0 | 0 | € - | € - | € 700,000.00 | € 7,000.00 |
| 1 | 1 | € 28,000.00 | € 35,000.00 | € 665,000.00 | € 63,000.00 |
| 2 | 2 | € 26,600.00 | € 35,000.00 | € 630,000.00 | € 61,600.00 |
| 3 | 3 | € 25,200.00 | € 35,000.00 | € 595,000.00 | € 60,200.00 |
| 4 | 4 | € 23,800.00 | € 35,000.00 | € 560,000.00 | € 58,800.00 |
| 5 | 5 | € 22,400.00 | € 35,000.00 | € 525,000.00 | € 57,400.00 |
| 6 | 6 | € 21,000.00 | € 35,000.00 | € 490,000.00 | € 56,000.00 |
| 7 | 7 | € 19,600.00 | € 35,000.00 | € 455,000.00 | € 54,600.00 |
| 8 | 8 | € 18,200.00 | € 35,000.00 | € 420,000.00 | € 53,200.00 |
| 9 | 9 | € 16,800.00 | € 35,000.00 | € 385,000.00 | € 51,800.00 |
| 10 | 10 | € 15,400.00 | € 35,000.00 | € 350,000.00 | € 50,400.00 |
| 11 | 11 | € 14,000.00 | € 35,000.00 | € 315,000.00 | € 49,000.00 |
| 12 | 12 | € 12,600.00 | € 35,000.00 | € 280,000.00 | € 47,600.00 |
| 13 | 13 | € 11,200.00 | € 35,000.00 | € 245,000.00 | € 46,200.00 |
| 14 | 14 | € 9,800.00 | € 35,000.00 | € 210,000.00 | € 44,800.00 |
| 15 | 15 | € 8,400.00 | € 35,000.00 | € 175,000.00 | € 43,400.00 |
| 16 | 16 | € 7,000.00 | € 35,000.00 | € 140,000.00 | € 42,000.00 |
| 17 | 17 | € 5,600.00 | € 35,000.00 | € 105,000.00 | € 40,600.00 |
| 18 | 18 | € 4,200.00 | € 35,000.00 | € 70,000.00 | € 39,200.00 |
| 19 | 19 | € 2,800.00 | € 35,000.00 | € 35,000.00 | € 37,800.00 |
| 20 | 20 | € 1,400.00 | € 35,000.00 | € - | € 36,400.00 |

Table 7 depicts the financial plan regarding the investment of the farm for the acquisition and installation of a biogas plant. The investment sum of **€1M** is based on a rough estimate offered by Finess Energy Oy based on the Bright Biomethane *PurePac* medium for a 500 $Nm^3/h$ treatment plant. Scaling it down to a 100 $Nm^3/h$ treatment plant we can safely assume a conservative investment of **700,000€**. A **4%** interest the investment is returned in 20 years with **20 installments**. The opening fees to start the payment plan are 1% of the total CAPEX and payed only once at the beginning of the process (year 0). We do not apply a subsidy in this case, since the government subsidies are intended for the construction of the biogas plant and not the compressed biomethane treatment plan. One of the reasons for this decision is that it is very difficult to assume such subsidies for projects involving biofuel for transportation. It is more realistic to neglect any subsidy for the time being regarding this scenario.

- **Revenue**
  - Compressed biogas sale (€/$Nm^3$ and €/year) - sales through service station, market or directly to suppliers.

As observed in table 8 and according to the manufacturers, the PurePac systems extracts **55%** of biomethane from the raw biogas with a purity of **98%**. This means **165,584.78 Nm$^3$ compressed biomethane/ year** are available for direct sale.

*Table 8 - Biomethane extraction and compression*

| BIOMETHANE EXTRACTION | |
|---|---|
| **raw biogas (Nm3/y)** | 301,063.23 |
| **biomethane content (%)** | 55% |
| **compressed biomethane (Nm3/y)** | 165,584.78 |

At an average price of **0.95€/l**, the plant can benefit from **157,305.54€/year**.

*<u>Note</u>: the service station and delivery costs are not included in this study.*

*Table 9 - Compressed biomethane revenue calculation*

| COMPRESSED BIOMETHANE REVENUE CALCULATIONS | |
|---|---|
| **biogas price (EUR/l)** | 0.95 |
| **biogas price (EUR/m3)** | 950 |
| **Biogas sale (EUR/year)** | 157,305.54 € |

- **Net cash flow and financial indicators**
  - Net cash flow accounting for the revenues minus the costs on each year.
  - IRR – as a percentage on a 20 year period.
  - Net present value (NPV) – with a discount rate equal to the interest rate of the debt funding (4%).

<u>Note</u>: for every scenario, a **1.2% inflation rate** is applied to the Euro currency (€). This percentage was obtained from the **European Central Bank on February 2020** (European Central Bank - EuroStat, 2020) – the date the model was on its initial stages.

# 4. Results

This chapter contains the results of the different business models depicted in the biogas plant installation scenarios.

## 4.1. Scenario 0 (Farm with no biogas plant)

The base scenario (scenario 0) is based on the farm business model embodied as the energy consumption. Since thermal energy is calculated based on machinery operation and fuel consumption for different farm equipment, only the electricity consumption is considered for this study.

*Table 10 - Farm energy consumption- adapted from LUKE economic study on Finnish farms (LUKE, 2018)*

| | Milk farms | | | | | | |
|---|---|---|---|---|---|---|---|
| | Dairy farms | | | | | | |
| | 2018 Economic size (EU measure of size, gross output) | | | | | | |
| | Average | 25,000_50,000 | 50,000_100,000 | 100,000_250,000 | 250,000_500,000 | 500.000_750,000 | 750,000_1,000,000 |
| **N of farms** | 6,260 | 180 | 1,770 | 2,890 | 1,070 | 210 | 40 |
| **Farms in sample** | 230<n<240 | 0<n<4 | 30<n<40 | 90<n<100 | 80<n<90 | 11<n<20 | 5<n<10 |
| **Arable land ha** | 77,5 | . | 37,5 | 75 | 134,8 | 171,7 | 266,6 |
| **Animal units** | 63 | . | 23.2 | 57.1 | 112.9 | 223 | 287.7 |
| **Producction cost total** | **354,920** | **.** | **159,539** | **329,163** | **600,282** | **1,059,246** | **1,542,143** |
| Fuel | 9,206 | . | 4,157 | 8,484 | 16,004 | 28,146 | 36,643 |
| Electricity | 6,691 | . | 3,309 | 6,010 | 11,622 | 20,476 | 21,691 |

The results show the annual electricity consumptions in euros. The 6th column (500,000-750,000) displays 223 animal units and was scaled down to a 200 animal units farm.

*Table 11 - Annual electricity costs for the 200 cow farm*

| ENERGY COSTS FARM (EUR/y) | |
|---|---|
| **ELECTRICITY COSTS** | -18,364.13 € |

Table 11 shows the estimated electricity costs for the farm. It would be circa **18,364.13 euros per year**. The biogas plant equipped with the CHP engine, has to have the potential to cover the electricity demand of the farm.

## 4.2. Scenario 1 – Biogas to CHP

By applying the biogas plant design from chapter 3.3 and the financial conditions from chapter 3.4, the following results reflect the feasibility of installing a biogas plant fed only by manure and grass silage.

The CHP engine is fed only the necessary biogas to cover the electricity demand. This accounts for **16.89% (61,186.77 Nm$^3$/year)** of the total biogas produced.

*Table 12 - gas demand farm*

| | | |
|---|---|---|
| demand farm electricity (adjusted to CHP losses and potential) | 389,759.70 | kWh/year |
| gas demand farm | 61,186.77 | Nm3 BG/year |
| gas demand farm (%) | 16.89% | |

*Table 13 - Energy production biogas plant CHP*

| ENERGY PRODUCTION | | |
|---|---|---|
| **CHP ELECTRICAL POWER** | 19.49 | kW |
| **CHP THERMAL POWER** | 29.23 | kW |
| **CHP OPERATING HOURS** | 8,000.00 | hours/year |
| **CHP ELECTRIC POWER GENERATED** | 155,903.88 | kWh/year |
| **CHP GENERATED THERMAL ENERGY** | 233,855.82 | kWh/year |
| **ELECTRICITY self-consumption (CHP)** | 8.70% | rate |
| **ELECTRICITY self-consumption (CHP)** | 13,563.64 | kWh/year |
| **ELECTRIC POWER AVAILABLE** | 142,340.24 | kWh/year |
| **ELECTRICITY DEMAND FARM** | 142,300.00 | kWh/year |
| **ELECTRICITY DEMAND COMPRESSED BIOGAS PLANT** | - | kWh/year |
| **TOTAL ELECTRICITY DEMAND** | 142,300.00 | kWh/year |
| **ELECTRICITY SURPLUS** | 40.24 | kWh/year |

Table 12 shows the energy production of the biogas plant. The thermal energy is only used to feed the bioreactor. The CHP engine produces **155,903.88 kWh/year** electricity and consumes about **8.70%** (Naegele, et al., 2012) of all the electricity produced. This leaves enough energy to power the farm electricity needs, at **142,300.00 kWh/year**.

The yearly cashflow is observed in table 14, where there is a constant loss of funds in order to pay the biogas plant investment in addition to the opportunity cost and operational costs of the installation. The farm would not be able to front the payments of the investment just be covering its annual electricity costs. The full detailed cash flow balance can be found in Appendix I.

*Table 14 – Annual cash flow scenario 1*

| YEAR | NET CASH FLOW | CUMULATIVE CASH FLOW |
|---|---|---|
| 0 | -6,928.16 € | -6,928.16 € |
| 1 | -66,989.32 € | -73,917.48 € |
| 2 | -67,044.95 € | -140,962.44 € |
| 3 | -64,329.99 € | -205,292.42 € |
| 4 | -63,001.33 € | -268,293.75 € |
| 5 | -61,673.35 € | -329,967.10 € |
| 6 | -60,346.07 € | -390,313.17 € |
| 7 | -59,019.49 € | -449,332.66 € |
| 8 | -57,693.61 € | -507,026.27 € |
| 9 | -56,368.46 € | -563,394.73 € |
| 10 | -55,044.02 € | -618,438.75 € |
| 11 | -53,720.33 € | -672,159.08 € |
| 12 | -52,397.37 € | -724,556.45 € |
| 13 | -51,075.17 € | -775,631.62 € |
| 14 | -49,753.73 € | -825,385.36 € |
| 15 | -48,433.06 € | -873,818.42 € |
| 16 | -47,113.17 € | -920,931.59 € |
| 17 | -45,794.07 € | -966,725.66 € |
| 18 | -44,475.77 € | -1,011,201.42 € |
| 19 | -43,158.27 € | -1,054,359.69 € |
| 20 | -41,841.59 € | -1,096,201.29 € |

### 4.2.1. Financial indicators results for Scenario 1

The financial indicators are calculated the following way:

i. The net cash flow excluding loan repayment is obtained. In year 0, the opening fees and the initial investment are categorized as a negative cash flow. From then onwards the annual returns are calculated from year 1 to year 20, consisting of the revenue minus the annual costs (operation, maintenance and opportunity costs). The investment capital costs are nto included since they are already depicted in year 0. The NPV is calculated directly on this cash flow for a period if **20 years** and a **discount rate of 4%**.

ii. The payback deficit is calculated by placing the CAPEX of the installations in year 0 as a negative cash flow, and then adding the annual net cash flows from point i) to the total deficit. This reveals the annual cash flow in relation with the initial investment and allows us to calculate the payback time and IRR. Positive values constitute returns on invested capital.

*Table 15 - Net cash flow from operations and payback deficit on capital investment for Scenario 1*

| YEAR | NET CASH FLOW (Excluding loan repayment) | PAYBACK DEFICIT |
|---|---|---|
| 0 | -699,744.24 € | -699,816.08 € |
| 1 | -4,635.87 € | -704,451.96 € |
| 2 | -4,691.50 € | -709,143.46 € |
| 3 | -4,747.80 € | -713,891.26 € |
| 4 | -4,804.78 € | -718,696.04 € |
| 5 | -4,862.43 € | -723,558.48 € |
| 6 | -4,920.78 € | -728,479.26 € |
| 7 | -4,979.83 € | -733,459.09 € |
| 8 | -5,039.59 € | -738,498.68 € |
| 9 | -5,100.07 € | -743,598.75 € |
| 10 | -5,161.27 € | -748,760.01 € |
| 11 | -5,223.20 € | -753,983.22 € |
| 12 | -5,285.88 € | -759,269.10 € |
| 13 | -5,349.31 € | -764,618.41 € |
| 14 | -5,413.50 € | -770,031.91 € |
| 15 | -5,478.46 € | -775,510.37 € |
| 16 | -5,544.21 € | -781,054.58 € |
| 17 | -5,610.74 € | -786,665.31 € |
| 18 | -5,678.07 € | -792,343.38 € |
| 19 | -5,746.20 € | -798,089.58 € |
| 20 | -5,815.16 € | -803,904.74 € |

The financial indicators show an undefined internal rate of return and payback time, since the initial investment an annual returns are negative. There is no payback time available within the 20 years lifespan of the plant. This shows that is not a feasible business for a 200 cow farm relying solely on electricity produced by a manure and grass silage feed. The net present value reveals a **€0.74M** loss for the company.

*Table 16 - Financial indicators scenario 1*

| | |
|---|---|
| IRR (%) | UNDEFINED |
| Payback (years) | UNDEFINED |
| NPV (4%) | -739,866.61 € |

## 4.3. Scenario 2 – Biogas to CHP and compressed biomethane production

The final scenario of the economic analysis studies the installation and construction of a biogas plant with a CHP engine to produce electricity for the farm and a compressed biomethane production plant. The compressed biomethane facility treats raw biogas from the bioreactor and produces biomethane, which is compressed and sold as fuel in the market. The *PurePac* compressed biomethane installation used for this study extracts 55% of biomethane from raw biogas with an availability of 98% (purity), as seen in chapter 3.4. In this scenario capital expenditure (CAPEX) of the compressed biomethane production plant is added to the existing one which was set up for the biogas plant itself (scenario 1). Costs involving the operation and maintenance are added to the existing OPEX from scenario 1. Finally, the opportunity costs from growing silage remains the same.

In terms of revenue, now the farm produces an income from the sale of compressed biomethane. Around **83.11% (301,063.23 Nm$^3$ BG/year)** of the total biogas produced is sent to the compressing plant to treat and retrieve **165,584.78 Nm$^3$ biomethane/year**. This is sold at **0.95€/l** generating a revenue of **157,305.54 €/year**. The detailed cashflows with its respective revenue and costs categories are found in Appendix II.

*Table 17 - Annual cash flows scenario 2*

| YEAR | NET CASH FLOW | CUMULATIVE CASH FLOW |
|---|---|---|
| 0 | -13,928.16 € | -13,928.16 € |
| 1 | -8,610.74 € | -22,538.90 € |
| 2 | -5,809.83 € | -28,348.73 € |
| 3 | -2,131.16 € | -30,479.89 € |
| 4 | 155.97 € | -30,323.93 € |
| 5 | 2,437.11 € | -27,886.82 € |
| 6 | 4,712.20 € | -23,174.62 € |
| 7 | 6,981.16 € | -16,193.46 € |
| 8 | 9,243.93 € | -6,949.53 € |
| 9 | 11,500.42 € | 4,550.89 € |
| 10 | 13,750.55 € | 18,301.44 € |
| 11 | 15,994.27 € | 34,295.71 € |
| 12 | 18,231.48 € | 52,527.19 € |
| 13 | 20,462.11 € | 72,989.30 € |
| 14 | 22,686.08 € | 95,675.37 € |
| 15 | 24,903.31 € | 120,578.68 € |
| 16 | 27,113.72 € | 147,692.40 € |
| 17 | 29,317.22 € | 177,009.62 € |
| 18 | 31,513.74 € | 208,523.36 € |
| 19 | 33,703.19 € | 242,226.55 € |
| 20 | 35,885.49 € | 278,112.04 € |

Table 17 shows the annual cash flows calculated in scenario 2. As observed, the business prospects of including a compressed biomethane as a product to sell in the market are relatively favorable for the farm model.

According to the model, for the first three years, the farm will not start producing a positive net cashflow. After that it will gradually increase its profits, due to the fact that the credit loan (investment) interest will decrease over the 20 year payment plan. Even though there is a combined CAPEX of **1.4 M€**, the revenue stream from the sale of compressed biomethane makes scenario 2 feasible.

### 4.3.1. Financial indicators results for Scenario 2

Calculated the same way as for scenario 1 (detailed explanation of method and execution in section 4.2.1), the annual net cash flows excluding loan repayment and payback deficit are obtained and used to calculate the IRR, NPV and Payback time.

*Table 18 - Net cash flow from operations and payback deficit on capital investment for Scenario 2*

| YEAR | NET CASH FLOW (Excluding loan repayment) | PAYBACK DEFICIT |
|---|---|---|
| 0 | -1,406,744.24 € | -1,406,744.24 € |
| 1 | 116,742.71 € | -1,290,001.54 € |
| 2 | 118,143.62 € | -1,171,857.92 € |
| 3 | 117,651.02 € | -1,054,206.90 € |
| 4 | 117,152.52 € | -937,054.38 € |
| 5 | 116,648.03 € | -820,406.35 € |
| 6 | 116,137.49 € | -704,268.87 € |
| 7 | 115,620.82 € | -588,648.05 € |
| 8 | 115,097.95 € | -473,550.10 € |
| 9 | 114,568.81 € | -358,981.30 € |
| 10 | 114,033.31 € | -244,947.98 € |
| 11 | 113,491.39 € | -131,456.59 € |
| 12 | 112,942.97 € | -18,513.62 € |
| 13 | 112,387.97 € | 93,874.35 € |
| 14 | 111,826.31 € | 205,700.66 € |
| 15 | 111,257.90 € | 316,958.56 € |
| 16 | 110,682.68 € | 427,641.25 € |
| 17 | 110,100.55 € | 537,741.80 € |
| 18 | 109,511.44 € | 647,253.24 € |
| 19 | 108,915.26 € | 756,168.50 € |
| 20 | 108,311.93 € | 864,480.43 € |

With an IRR (internal rate of return) of **5.16%** and a payback time of 12 years, the business model shows strength. The strength relies on the sales of biomethane. The NPV with a discount rate of **4%** is **139,950.87 €**.

*Table 19 - Financial indicators scenario 2*

| | |
|---|---|
| IRR (%) | 5.16% |
| Payback (years) | 12 |
| NPV (4%) | 139,950.87 € |

## 4.4. Sensitivity analysis

In order to understand the way the model works and its limitations, it is important to do a sensitivity analysis of the different scenarios. In this case, scenario 1 and 2 are analyzed concerning the values stated in the method chapter. This means, that the starting values are the ones assigned to each scenario and a set of independent variables are studied each time. The independent variables maximum or minimum value to reach a certain goal are calculated. The variables are grouped in two different analysis. For example: to achieve an NPV>0 in scenario 2, what is the minimum sale price of compressed biomethane?

The goals were set assuming the minimum financial values of a business for it to be feasible in a farm setting. Thus, the following minimum (conservative) values were chosen:

iii. NPV (4%) – 0 and 100,000€

iv. Payback time – 12 years

v. IRR – 10%

*Table 20 - Scenario 1 sensitivity analysis*

| SET GOAL | Independent variable change to reach goal | | | |
|---|---|---|---|---|
| | ANALYSIS 1 | | ANALYSIS 2 | |
| NPV(4%) | Biogas plant CAPEX (EUR) | Electricity savings farm (EUR/year) (basic conditions) | Biogas plant CAPEX (EUR) (basic conditions | Electricity savings farm (EUR/year) |
| 0 | 322,000.00 € | 18,364.13 € | 800,000.00 € | 23,475.00 € |
| 100,000 | NO EFFECT | 18,364.13 € | 800,000.00 € | 30,500.00 € |
| Payback (y) | | | | |
| 12 | NO EFFECT | 18,364.13 € | 800,000.00 € | 97,000.00 € |
| IRR | | | | |
| 10% | NO EFFECT | 18,364.13 € | 800,000.00 € | 108,500.00 € |

Table 20 shows the results of the sensitivity analysis of scenario 1. The biogas plant capital investment has no little to no effect on the payback time (12y) and IRR (10%). Even if the plant was free (0€), a payback time of 12 years or a 10% IRR would not be achieved. This si due to the high opportunity costs from grass silage. To reach a NPV of 0, the plant has to cost no more than **322,000.00 €**.

The sensitivity analysis shows that in order for the plant to obtain a positive net present value, the electricity savings should be at least **23,475.00 €/year**. If the NPV goal is set at 100,000 €, this quantity must increase to **30,500.00 €/year**.

For a payback time of 12 years the electricity savings should be around **97,000.00 €/year** and for an IRR of 10%, the electricity accounts for at least **108,500.00 €/year**. This of course, is a very difficult requirement to reach in 200 cow farms but more feasible in larger installations. Overall, the model confirms that scenario 1 is highly dependent on electricity savings for it be feasible.

*Table 21 - Scenario 2 sensitivity analysis*

| SET GOAL | Independent variable change to reach goal | | | |
|---|---|---|---|---|
| | ANALYSIS 1 | | ANALYSIS 2 | |
| NPV (4%) | Compressed biomethane price (EUR/l) | Electricity savings farm (EUR/year) (basic conditions) | Compressed biomethane price (EUR/l) (basic conditions) | Electricity savings farm (EUR/year) |
| 0 | 0.89 € | 18,364.13 € | 0.95 € | 8,680.00 € |
| 100,000 | 0.93 € | 18,364.13 € | 0.95 € | 15,600.00 € |
| Payback (y) | | | | |
| 12 | 0.88 € | 18,364.13 € | 0.95 € | 11,700.00 € |
| IRR (%) | | | | |
| 10% | 1.25 € | 18,364.13 € | 0.95 € | 64,645.00 € |

Table 21 shows the results obtained from the sensitivity analysis of scenario 2. The addition of the compressed biomethane treatment plant makes the minimum values rather flexible in terms of subsidy and electricity savings.

However, the sale price of compressed biomethane must be at least **0.89 €/l** in order for the NPV to be over 0. In order to obtain a more attractive NPV, let's say of **100,000 €,** the price must be at least **0.93 €/l**. This latter value is similar to that in order to obtain a payback time of at least 12 years. However, to reach a 10% IRR, the price must jump 30 cents per liter to 1.25 €/l. Overall, the compressed biomethane price must range **0.88 – 0.93 €/l** in order to reach the desired goals and make the business feasible. This means that scenario 2 is very dependent on compressed biomethane prices and can be affected in the case that prices or demand drop.

For that reason, the electricity savings for the farm become a secondary factor this time. In contrast with scenario 1, the electricity saving should range the **11,000 €/year** mark. This is a realistic assumption considering the values obtained from the LUKE report on Finnish dairy farm energy costs (18,000 €/year). Biomethane sales allow the farm to lower the biogas plant electricity generation.

# 5. Discussion

This chapter addresses the procedure undertaken in order to come up with the aforementioned results. Interpreting, analyzing and connecting the results with the thesis goal is the main objective of the discussion. Critical feedback to the protocol and method is vital in order to improve the quality of the study and propose further recommendations.

The goal of the thesis was to assess the best type of biogas business model for a 200 cow farm, considering its availability of resources. Cow manure and grass silage were the designated resources based on the general dairy farm structure in the Finnish agricultural sector. The most feasible business model happened to be scenario 2, where a biogas plant was installed in combination with a CHP engine to produce electricity and a post-treatment plant to produce compressed biomethane. It was the only scenario which has proved to yield a return for the business, since scenario 1 gave an undefined payback time (negative returns). This results pose a relatively high level of uncertainty due to the amount of assumptions which were put into them. For that reason, it is important to take them with caution and analyze the different steps in the method.

## 5.1. Farm model design

The farm model was embodied only as electricity costs, which served for the purpose of simplifying the farm business model. The only operations that were affected by the biogas plant model in theory, were those related to energy consumption. It was revealed by the Luke dairy farm economic report (2018) that 200 cow farms consume around 18,000 euros in electricity per year. This of course, can vary from site to site and in this thesis analysis, it was scaled from an original 223 animal unit average. The reason why thermal energy consumption by the farm was neglected is due to the fact that dairy farms require very little thermal energy to heat up the cow sheds, since they rely on electricity and animal heat to do so. The thermal energy estimations found on the literature lied predominately on fuel costs for operating the farm machinery. Of course, the biogas plant cannot fulfill those requirements unless they run on compressed biomethane. For that reason, electricity was the only farm cost considered in the study. This factor conditions the flexibility and benefits of the biogas plant installation itself, restricting the CHP engine's use. Thus, I believe it has influenced the negative economic outcome of scenario 1. A way to improve this farm model is to study the energy consumption of an actual 200 cow farm and include the different detailed cash flows in the model. This would bring a more realistic approach for the Finnish case study which is intended in the Master's thesis. Seeing the bigger picture can put the business model into perspective and retrieve results addressing both the thermal and electricity consumption. In a future study, it is recommended that a model is created from real-life farms, either from a single farm or an average obtained from several farms. Furthermore, it should be randomized in terms of location or focus on a single region of Finland (an area where many farms are located).

The second biggest issue with designing the farm was considering the hectares of crop fields and production of grass silage. These are very important factors since they determine the opportunity costs and biogas potential. The opportunity cost was calculated by assuming a 25% dry matter content in the grass silage. Thus, 500 tons of fresh silage contain 125 tons of dry matter that can be sold at a certain price in the market, meaning it is an opportunity cost. Both scenarios were approached by assuming that the plant requires the fixed quantity of 500 tons of grass silage, without considering the implications for the farm economy and the feasibility of growing such quantity expressly for the biogas plant. The fixed rate of grass silage works very well for scenario 2, where the goal is to produce as much biomethane as possible to be able to sell it and obtain a large profit. However, it is detrimental for scenario 1, where electricity for the farm is the determining factor in the business model. In order to improve the financial model it is necessary to consider using only the necessary amount of grass silage that is required to cover the farm's electricity demand. This would lower the opportunity costs and make the model more financially attractive. For further research it is recommended to adapt the grass silage production to each scenario according to the model dynamics and the business goals.

## 5.2. Biogas plant design

The biogas plant treats 5000 tons of cow manure and 500 tons of grass silage produced by the farm, on two digesters of 1222.22 $m^3$ each with a 40 day retention time. The biogas plant produced circa 360,000 $Nm^3$ of biogas per year based on the feed biogas potential. The results were favorable in terms of biogas production. Nonetheless, this calculations must be taken with caution. There is always variations depending on the source and method utilized.

It may be possible that the biogas and methane yields may vary from site to site. For example this variation can be seen in different studies and models:

1. BITECO BIOGAS CALCULATOR estimated a production of less than half the amount that was obtained in this thesis. The estimation was 148,000 $Nm^3$/year for 5000 tons of manure and 500 tons of grass silage (BITECO, 2020).
2. LUKE's Biokaasulakuri (biogas calculator) estimates a methane yield of 177,000 $Nm^3$/year close to the 165,584 $Nm^3$ obtained in this thesis. Their reactor size is similar to that calculated in this study, with 1287 $m^3$. This gives certain validation to the results from the business model (LUKE, 2020).

Concerning the combined heat and power unit (CHP engine), it was assumed that the engine itself consumes 8.70% of the generated electricity for its own and the biogas plant operation. This was based on an article by Naegele et al. (2012) where they studied the performance and efficiency of biogas CHP units. This percentage was added to the farm energy demand, leaving a ca. 62,000 $Nm^3$ BG/y supply to the CHP engine or 16.89% of the total biogas produced. However, determining the energy efficiency of the biogas plant can be rather challenging. As pointed out in a literature study by Havukainen et al (2014) titled: '*Evaluation of methods for estimating energy performance of biogas production'*, the parasitic energy demand from the biogas plant itself differs greatly across different literature. For example, Laaber et al. (2007) determined that the parasitic electricity demand of 41 biogas plants in Austria accounted for only 2.7% of the total energy produced. This value would fit with the model studied in this thesis. Nonetheless, other studies suggest that the energy efficiency is much lower as biogas plants require high amounts of electricity and heat to function. Tuomisto and Helenius (2008) calculated a median range of 22-37% of the total electricity produced, whilst Posch et al. (2010) came up with a wider range of 10.5-64%.

This reveals that it is very complicated to assume theoretically the electricity consumption of a biogas plant without obtaining a direct quotation or design from a biogas engineering firm. Mainly, because this information is lacking in the literature (Havukainen, et al., 2014). Another solution to design a more reliable model, would be to obtain a formula or preexisting template that could calculate the energy consumption based on the dimensions of the biogas plant.

## 5.3. Scenario 1 – Biogas for electricity production

The economic model revealed that scenario 1, where biogas is produced for the sole intent of covering the electricity demand of the farm, is not economically feasible. The net present value was almost negative one million and there was no defined rate of return, meaning that the costs of installing and operating the biogas plant are much higher than the actual generated savings. The factors influencing this condition were the relatively low electricity savings, the opportunity costs of producing grass silage and the high capital expenditure of the biogas plant installation. In 20 years, there is no margin for generating profit. The results must be taken cautiously due to the limiting conditions of this specific scenario model.

Firstly, the biogas plant capital expenditure is assumed based on conservative estimations. The costs of investment are substantial (800,000 €) and the subsidy covers circa 13% of the installation costs. As other models suggest, subsidies from Finnish authorities could account for up to 40% of the total investment. In addition to restrictive financial conditions, the thermal energy from the farm is not covered by the plant, limiting the model even further. As explained in chapter 3.4, the lack of incentives to sell the generated electricity to the grid, makes it difficult for smaller biogas plants to benefit from producing energy. In other countries like Argentina, power purchase agreements (PPAs) allow the biogas plants to sell their electricity at a set price with a guaranteed long-term contract. Known as *Plan RenovAr*, the Argentinian government provides renewable energy producers a set of PPAs (with an electricity price higher than the market standard) in order to enhance the development of renewable energy projects in the country (Government of Argentina, 2017). Biogas producers are part of the target business. In Finland however, the limitations for feeding electricity on to the grid and the tariff system, make it impossible for farmers to sell their electricity (Rolamo & Jarvinen, 2017). From an economist perspective, this system is very restricting to the small renewable energy producers as they require very large installations that they cannot afford to build.

The second limiting factor in this model, is the fact that the production of grass silage is not adjusted to the electricity demand of the farm. This means that a standard 500 ton of silage is produced, more than what the plant actually needs to generate the electricity necessary for farm use. This leaves an unnecessary and avoidable opportunity cost that negatively impacts the financial plan. For a more realistic approach, it is recommended that the grass silage is grown only to generate the minimum electricity to cover the farm's needs. This would, most certainly, reduce the financial strain of the model and improve scenario 1.

The possibility of using excess electricity to sell to the grid (at a reduced price) or used to power up the housing buildings in the farm premises were initially considered. However, realistically speaking, it would not yield much revenue nor savings for the farm. From a bookkeeper perspective it is a negligible amount if compared to the bigger picture, where approximately 1 million euro is being invested through a credit loan. Opportunity and operational costs, even if partially covered by housing electricity savings and grid sales, it would still not cover the monthly expenses of repaying the debt. This situation changes if the capital expenditure is much lower or if a feed with higher methane potential is used, rather than cow manure and grass silage only.

However, from an environmental economist perspective, diversifying the cash flows and business opportunities of the model can bring great benefits to the circularity and economic potential of biogas energy production. If more beneficial conditions are established (such as lower operational, capital and opportunity costs; higher subsidies and compensations for the electricity produced), an inclusive business model that incorporates the idea of covering the home electricity demands and provides electricity to the grid enhances the sustainability of the economy. The business model would also be reinforced, as it would not depend on changes in the market (prices) or producing large amounts of alternative products (biofuels or biofertilizers). As seen on the theoretical background (chapter 2.1), a circular economy is achieved by producing added value by reducing the waste of production. The utilization of heat would also be possible in this biogas plant set-up, according to the retrieved data it would improve the financial feasibility of the business model. Heating costs are usually grouped together with fuel costs, so it is difficult to assume on a theoretical scale.

## 5.4. Scenario 2 – Compressed biomethane and electricity production

By installing a post-treatment plant at the biogas facility in order to produce compressed biomethane and sell it in the market, the business model gains in feasibility. The results show a pay-back time of 12 years and a IRR of 5.16%. These numbers are more favorable than the previous scenario and show that diversifying the model provides a more robust financial outcome. Nonetheless, these results must be taken cautiously. The reason for this is that many assumptions are not as realistic as hoped for in terms of capital expenditure and operating costs.

The operation and maintenance costs are scaled down from those belonging to a much larger treatment plant (5x treating capacity). The concrete values for a smaller, 100 $Nm^3/h$ treatment facility are unknown. Furthermore, the CAPEX of the plant was based on a pure assumption by conservatively approaching the quotation offered by *Finess Oy* on the larger 500 $Nm^3/h$ plant (which was valued at 1 million euros). This uncertainty could go both ways: either the installation costs are much higher than the assumed 700,000 euros and the business model has been underestimated or they are much lower and the business model has been overestimated. Either way, it is very difficult to pinpoint an exact cost for these kind of installations without obtaining an official quotation by an engineering firm. Costs vary across locations and cases, and they must always be taken cautiously.

From a bookkeeper perspective, the business model is very dependent on compressed biomethane prices, as expected. The core of the financial model lies on the sales of the treated biogas to the market. This means that the business will work as long as the gas prices stay in the 0.928€/liter range. If prices should go down, as shown in the sensitivity analysis (see chapter 4.4), the payback time would be larger than 12 years and the NPV will approach 0. Although Finland's economy is rather stable, the gas prices are heavily influenced by the global gas market. In recent years, the prices have been volatile and constantly changing due to geo-political events (OPEC, 2009). For example, in the time this report is being written, the natural gas price stands at 0.763€/l whilst biomethane stands at 0.955€/l (Gasum, 2020). Competing with natural gas poses some obstacles, as customers tend to lean on the cheapest fuel. Ensuring a safe investment can be challenging in these market conditions, however, according to the model it is the most strategically feasible scenario a biogas plant can offer to a 200-cow farm.

Overall, biogas plants offer a variety of business opportunities from energy production and by-product processing. On a large scale, it reduces the carbon footprint of dairy farming. This is observed in the production of self-harvested, renewable energy that can substitute fossil fuel sources. Furthermore, compressed biomethane has the capability to fully take over natural gas fuels, however, when combusted it still contributes to the greenhouse gas effect. In order to fully understand the role of the biogas plant as a carbon footprint mitigator for dairy farms, it is necessary to analyze the greenhouse gas balance of the process (with and without the biogas plant). The plant life cycle plays an important role mainly because it requires heavy construction, maintenance and has a 20 year life span. All of these variables must be taken into account, although in the bigger picture, it shows potential to reduce the carbon footprint of dairy farms. Other applications are available in the biogas plant facilities. Manure digestate can be processed to produce biofertilizers. Biofertilizers can be produced in accordance to the farm need's and can help boost the production of crops. Furthermore, they can be sold in the market for a substantial revenue. By extracting and concentrating the nutrients from the digestate (nitrogen, phosphorus and potassium), a very nutrient rich fertilizer can be produced. This would add value to the business model and certainly enhance the societal value of the project.

# 6. Conclusion

To conclude, the model revealed that a dairy farm with 200 animal units that feeds cow manure and grass silage to a biogas plant should invest in biofuels to be able to recover the initial investment and make a profit in the long run. The lack of incentives to sell electricity in the Finnish system, conditions the business prospects to lean on alternative revenue streams rather than energy production. In this study, two scenarios were compared. The first one studied the construction of a digester coupled with a CHP unit to produce electricity to cover the farm needs. The second incorporated a post-treatment unit that converted biogas into compressed biomethane to be sold in the market. Both financial scenarios were projected using an assumed CAPEX (based on lose market references) with a 4% interest rate to be paid in 20 years.

Scenario 1 was financially unfeasible due to the large biogas plant construction costs and opportunity costs derived from grass silage production. In addition to the costs, the electricity savings the plant provided were not sufficient to cover the investment, thus, yielding a negative internal rate of return. The subsidy was calculated using a conservative approach (with the Finnish Energy Authority subsidy template) and it stood at **13.4%** of the **800,000** initial investment. This subsidy was only applied to the biogas plant.

Scenario 2 proved to be financially feasible due to the income obtained from the sale of large quantities of compressed biomethane but the projections were slightly suppressed by the high operational costs of the biogas treatment plant. The IRR stood at **5.16%** with a pay-back time of **12 years** and a NPV of circa **140,000€**. The sensitivity analysis showed that the business model is highly dependent on biofuel price, where a minimum price of **1.25 €/l** is needed to retain an IRR of at least 10% and **0.88 €/l** to retain 12 years payback time. The safe range to keep the model afloat lies in prices **above 0.89€/l.**

However, the results must be taken with caution as they are heavily based on assumptions. There are several incongruencies in the model that affect the reliability of the data. Firstly, only the electricity costs are considered as potential savings for the farm business model. These factor conditions the biogas plant model as there is a chance that thermal energy could be utilized, but this is unknown in the context of this study. Furthermore, the biogas plant and CHP engine energy consumption are very hard to assume due to the lack of consistent and concrete data available in the literature (Havukainen, et al., 2014). The parasitic consumption varies greatly among installations, in the wide range of 10-65%. Finally, the silage production was set up to favor biogas business models that require the production of the largest amount of biogas possible. This means that scenario 1 was impaired by the model. To produce only the necessary electricity to cover the farm's needs, a smaller amount of grass silage is needed. If applied fairly, the opportunity costs would be lower in scenario 1 and improve the prospects.

For future research it is important to improve the data reliability by obtaining concrete quotations for the design of a specific biogas installation in Finland. Its technical features and energy balances are vital for understanding the energy demand of the installations. Furthermore, a real farm should be studied as it would be offer a more realistic and precise approach in designing the business model in relation to energy consumption. Studying the options of energy sale (electricity) is not recommended unless the Finnish tariff system becomes more flexible with small scale biogas plants and their reduced energy potential.

Overall, the many alternatives and options biogas plants have to offer reinforce the prospects of a biogas plant business model. In many cases, however, it does not apply for businesses with low energy demand and limited production of biowaste. Nonetheless, its flexibility in terms of revenue stream diversification and added societal value from carbon footprint reduction, make it an attractive business to invest in. Biofertilizers can be produced from processed manure in addition to the compressed biomethane, with no impact on the overall biogas production. Additionally, heat and electricity can be harnessed to cover the demands from the main business unit, substituting fossil fuel sources in the process. Still, the entrepreneur has to make his decision based on the economic feasibility of the project, which in essence, it is the core focus of this Master’s thesis.

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# Appendix I – Cash flows from Scenario 1

Y 1-10

| REVENUE (EUR/y) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity saved | 0.00 € | 18,364.13 € | 18,584.50 € | 18,807.51 € | 19,033.20 € | 19,261.60 € | 19,492.74 € | 19,726.65 € | 19,963.37 € | 20,202.93 € | 20,445.36 € |
| TOTAL REVENUE (EUR/y) | 0.00 € | 18,364.13 € | 18,584.50 € | 18,807.51 € | 19,033.20 € | 19,261.60 € | 19,492.74 € | 19,726.65 € | 19,963.37 € | 20,202.93 € | 20,445.36 € |
| | | | | | | | | | | | |
| COSTS (EUR/y) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Biogas plant investment plan | -6,928.16 € | -62,353.45 € | -62,353.45 € | -59,582.18 € | -58,196.55 € | -56,810.92 € | -55,425.29 € | -54,039.65 € | -52,654.02 € | -51,268.39 € | -49,882.76 € |
| Biogas plant OPEX | 0.00 € | -8,000.00 € | -8,096.00 € | -8,193.15 € | -8,291.47 € | -8,390.97 € | -8,491.66 € | -8,593.56 € | -8,696.68 € | -8,801.04 € | -8,906.65 € |
| Opportunity costs (grass silage) | 0.00 € | -15,000.00 € | -15,180.00 € | -15,362.16 € | -15,546.51 € | -15,733.06 € | -15,921.86 € | -16,112.92 € | -16,306.28 € | -16,501.95 € | -16,699.98 € |
| TOTAL COSTS | -6,928.16 € | -85,353.45 € | -85,629.45 € | -83,137.50 € | -82,034.53 € | -80,934.95 € | -79,838.81 € | -78,746.14 € | -77,656.98 € | -76,571.39 € | -75,489.39 € |
| | | | | | | | | | | | |
| NET CASH FLOW | -6,928.16 € | -66,989.32 € | -67,044.95 € | -64,329.99 € | -63,001.33 € | -61,673.35 € | -60,346.07 € | -59,019.49 € | -57,693.61 € | -56,368.46 € | -55,044.02 € |
| CUMULATIVE CASH FLOW | -6,928.16 € | -73,917.48 € | -140,962.44 € | -205,292.42 € | -268,293.75 € | -329,967.10 € | -390,313.17 € | -449,332.66 € | -507,026.27 € | -563,394.73 € | -618,438.75 € |

Y 11-20

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| 20,690.71 € | 20,939.00 € | 21,190.27 € | 21,444.55 € | 21,701.88 € | 21,962.31 € | 22,225.85 € | 22,492.56 € | 22,762.47 € | 23,035.62 € |
| 20,690.71 € | 20,939.00 € | 21,190.27 € | 21,444.55 € | 21,701.88 € | 21,962.31 € | 22,225.85 € | 22,492.56 € | 22,762.47 € | 23,035.62 € |
| | | | | | | | | | |
| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| -48,497.13 € | -47,111.49 € | -45,725.86 € | -44,340.23 € | -42,954.60 € | -41,568.96 € | -40,183.33 € | -38,797.70 € | -37,412.07 € | -36,026.44 € |
| -9,013.53 € | -9,121.70 € | -9,231.16 € | -9,341.93 € | -9,454.03 € | -9,567.48 € | -9,682.29 € | -9,798.48 € | -9,916.06 € | -10,035.05 € |
| -16,900.38 € | -17,103.18 € | -17,308.42 € | -17,516.12 € | -17,726.31 € | -17,939.03 € | -18,154.30 € | -18,372.15 € | -18,592.62 € | -18,815.73 € |
| -74,411.04 € | -73,336.37 € | -72,265.44 € | -71,198.28 € | -70,134.95 € | -69,075.48 € | -68,019.92 € | -66,968.33 € | -65,920.75 € | -64,877.22 € |
| | | | | | | | | | |
| -53,720.33 € | -52,397.37 € | -51,075.17 € | -49,753.73 € | -48,433.06 € | -47,113.17 € | -45,794.07 € | -44,475.77 € | -43,158.27 € | -41,841.59 € |
| -672,159.08 € | -724,556.45 € | -775,631.62 € | -825,385.36 € | -873,818.42 € | -920,931.59 € | -966,725.66 € | -1,011,201.42 € | -1,054,359.69 € | -1,096,201.29 € |

# Appendix II – Cash flows from Scenario 2

Y 1-10

| REVENUE (EUR/y) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity saved | 0.00 € | 18,364.13 € | 18,584.50 € | 18,807.51 € | 19,033.20 € | 19,261.60 € | 19,492.74 € | 19,726.65 € | 19,963.37 € | 20,202.93 € | 20,445.36 € |
| Compressed biogas sale | 0.00 € | 157,305.54 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € |
| TOTAL REVENUE (EUR/y) | 0.00 € | 175,669.67 € | 177,777.70 € | 178,000.72 € | 178,226.41 € | 178,454.80 € | 178,685.94 € | 178,919.86 € | 179,156.58 € | 179,396.14 € | 179,638.57 € |

| COSTS (EUR/y) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Biogas plant investment plan | -6,928.16 € | -62,353.45 € | -62,353.45 € | -59,582.18 € | -58,196.55 € | -56,810.92 € | -55,425.29 € | -54,039.65 € | -52,654.02 € | -51,268.39 € | -49,882.76 € |
| Biogas plant OPEX | 0.00 € | -8,000.00 € | -8,096.00 € | -8,193.15 € | -8,291.47 € | -8,390.97 € | -8,491.66 € | -8,593.56 € | -8,696.68 € | -8,801.04 € | -8,906.65 € |
| Compressed biogas plant investment plan | -7,000.00 € | -63,000.00 € | -61,600.00 € | -60,200.00 € | -58,800.00 € | -57,400.00 € | -56,000.00 € | -54,600.00 € | -53,200.00 € | -51,800.00 € | -50,400.00 € |
| Compressed biogas plant OPEX | 0.00 € | -35,926.96 € | -36,358.08 € | -36,794.38 € | -37,235.91 € | -37,682.74 € | -38,134.94 € | -38,592.56 € | -39,055.67 € | -39,524.33 € | -39,998.63 € |
| Opportunity costs (grass silage) | 0.00 € | -15,000.00 € | -15,180.00 € | -15,362.16 € | -15,546.51 € | -15,733.06 € | -15,921.86 € | -16,112.92 € | -16,306.28 € | -16,501.95 € | -16,699.98 € |
| TOTAL COSTS | -13,928.16 € | -184,280.41 € | -183,587.53 € | -180,131.88 € | -178,070.44 € | -176,017.69 € | -173,973.74 € | -171,938.69 € | -169,912.65 € | -167,895.72 € | -165,888.02 € |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NET CASH FLOW | -13,928.16 € | -8,610.74 € | -5,809.83 € | -2,131.16 € | 155.97 € | 2,437.11 € | 4,712.20 € | 6,981.16 € | 9,243.93 € | 11,500.42 € | 13,750.55 € |
| CUMULATIVE CASH FLOW | -13,928.16 € | -22,538.90 € | -28,348.73 € | -30,479.89 € | -30,323.93 € | -27,886.82 € | -23,174.62 € | -16,193.46 € | -6,949.53 € | 4,550.89 € | 18,301.44 € |

Y 11-20

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| 20,690.71 € | 20,939.00 € | 21,190.27 € | 21,444.55 € | 21,701.88 € | 21,962.31 € | 22,225.85 € | 22,492.56 € | 22,762.47 € | 23,035.62 € |
| 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € | 159,193.21 € |
| 179,883.92 € | 180,132.20 € | 180,383.47 € | 180,637.76 € | 180,895.09 € | 181,155.51 € | 181,419.06 € | 181,685.77 € | 181,955.68 € | 182,228.83 € |

| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| -48,497.13 € | -47,111.49 € | -45,725.86 € | -44,340.23 € | -42,954.60 € | -41,568.96 € | -40,183.33 € | -38,797.70 € | -37,412.07 € | -36,026.44 € |
| -9,013.53 € | -9,121.70 € | -9,231.16 € | -9,341.93 € | -9,454.03 € | -9,567.48 € | -9,682.29 € | -9,798.48 € | -9,916.06 € | -10,035.05 € |
| -49,000.00 € | -47,600.00 € | -46,200.00 € | -44,800.00 € | -43,400.00 € | -42,000.00 € | -40,600.00 € | -39,200.00 € | -37,800.00 € | -36,400.00 € |
| -40,478.61 € | -40,964.35 € | -41,455.93 € | -41,953.40 € | -42,456.84 € | -42,966.32 € | -43,481.92 € | -44,003.70 € | -44,531.74 € | -45,066.12 € |
| -16,900.38 € | -17,103.18 € | -17,308.42 € | -17,516.12 € | -17,726.31 € | -17,939.03 € | -18,154.30 € | -18,372.15 € | -18,592.62 € | -18,815.73 € |
| -163,889.65 € | -161,900.73 € | -159,921.36 € | -157,951.68 € | -155,991.78 € | -154,041.80 € | -152,101.84 € | -150,172.03 € | -148,252.49 € | -146,343.34 € |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15,994.27 € | 18,231.48 € | 20,462.11 € | 22,686.08 € | 24,903.31 € | 27,113.72 € | 29,317.22 € | 31,513.74 € | 33,703.19 € | 35,885.49 € |
| 34,295.71 € | 52,527.19 € | 72,989.30 € | 95,675.37 € | 120,578.68 € | 147,692.40 € | 177,009.62 € | 208,523.36 € | 242,226.55 € | 278,112.04 € |